## Contents

# 1 Atlantic surfclam Assessment

## 1.1 Terms of reference

# Terms of Reference

**Management Track Assessment TORs** (Based on: Operational Assessment Process White Paper, 2011, Description of New England and Mid-Atlantic Region Stock Assessment Process, 2018, and NEFSC edits. v.01/14/2020)

1. Estimate catch from all sources including landings and discards
2. Evaluate indices used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.).
3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) as possible (depending on the assessment method) for the time series using the approved assessment method and estimate their uncertainty. Include retrospective analyses if possible (both historical and within-model) to allow a comparison with previous assessment results and projections, and to examine model fit.
   (a) Include bridge runs to sequentially document each change[1] from the previously accepted model to the updated model proposed for this peer review.
   (b) Prepare a "Plan B" assessment that would serve as an alternate approach to providing scientific advice to management if the analytical assessment were to not pass review.
4. Re-estimate or update the BRP's as defined by the management track level and recommend stock status. Also, provide qualitative descriptions of stock status based on simple indicators/metrics (e.g., age- and size-structure, temporal trends in population size or recruitment indices, etc.).
5. Conduct short-term stock projections when appropriate.
6. Respond to any review panel comments or SSC concerns from the most recent prior research or management track assessment.

[1]Major changes from the previous stock assessment require pre-approval by the Assessment Oversight Panel.

### 1.2 TOR 1: Commercial

In this assessment for Atlantic surfclam the northern area was federal waters (3-200 nm from shore) on Georges Bank and the southern area was federal waters from south and west of Georges Bank to Cape Hatteras (Figures 1 and 2). Commercial landings were provided in meat weights for ease of comparison to survey data and in analyses, but were originally reported in units of industry cages. Landings per unit of fishing effort (LPUE) data were reported in this assessment as landings in bushels per hour fished, based on mandatory clam logbook reports. The spatial resolution of the clam logbook reports was usually one ten-minute square.

| Unit | Equivalent |
|---|---|
| 1 cage | 32 bushels |
| 1 bushel | 1.88 $ft^3$ |
| 1 bushel | 17 lbs. meats |
| 1 bushel | 7.71 kg meats |

As in previous stock assessments (Northeast Fisheries Science Center 2017a), "catch" was defined as the sum of landings, plus 12% of landings, plus discards. Based on prior calculations (Northeast Fisheries Science Center 2003), Atlantic surfclam catch in previous assessments was assumed to be 12% larger than landings to account for incidental mortality of clams in the path of the dredge. The 12% figure was considered an upper bound or overestimate because the area fished (e.g. 155 $km^2$ during 2004) is small relative to area covered by the stock (Walace and Hoff 2005). Furthermore, the ITQ (see below) clam fishery operates with little or no regulation induced inefficiency due to area closures, trip limits, size limits, etc. so that fishing effort and incidental mortality are reduced. The support for this estimate was reevaluated in Northeast Fisheries Science Center 2017a based on data also used by Northeast Fisheries Science Center (2003), and more realistic algebraic relationships proposed by Dr. Deborah Hart (NEFSC, Woods Hole, MA) for sea scallops in Northeast Fisheries Science Center (2014).

The ratio of Atlantic surfclam in the path of a commercial dredge that are caught relative to those killed but not caught is $R = \frac{e}{c(1-e)}$ where e is capture efficiency and c is the fraction that die but are not caught. Indirect mortality due to contact with a clam dredge is in the range of 5-20% with an extreme upper bound of 50% (Table C10, (Northeast Fisheries Science Center 2003)). If $F_L$ is fishing mortality for landed Atlantic surfclam and $F_I$ is the incidental mortality rate then $F_I = \frac{F_L}{R} = \frac{F_L c(1-e)}{e}$ and $\frac{F_I}{F_L} = \frac{c(1-e)}{e}$. The ratio $\frac{F_I}{F_L}$ is the same as the ratio of numbers landed to numbers killed but not caught. If landed and incidental clams have the same size composition, then the ratio of landed weight to incidental weight is also $\frac{F_I}{F_L}$. The average efficiency of a commercial clam dredge for Atlantic surfclam is about 0.73 (Table A10 in NEFSC 2003). The range of estimates $c = 0.05$, 0.2 and 0.5 indicate that incidental losses are 2%, 7% and 18% of landings which together average about 13%. The Subcommittee concluded that the 12% incidental mortality estimate was reasonable for Atlantic surfclam.

Recreational catch is near zero, although small numbers of Atlantic surfclam are taken recreationally in shallow inshore waters for use as bait. Atlantic surfclam are not targeted recreationally for human consumption.

### Discard data

A small amount of bycatch of Atlantic surfclam occurs in the ocean quahog fishery although there is strong incentive not to fish in areas where both species occur, as mixed loads of ocean quahogs and Atlantic surfclam are not allowed under current regulations, and it is not currently practical to sort catches at sea. Fisheries Observers aboard 16 ocean quahog trips between 2004 and 2006 reported discarded Atlantic surfclam averaged about 100 pounds per trip. No clam trips were observed between 2007 and 2014, but observers began accompanying clam trips again in 2015. Using Standardized Bycatch Reporting Methodology (Tholke et al. 2017), Atlantic surfclam discards have been included in as a component of catch in this assessment. Typically they contribute a small amount to the total catch ($< 5\%$) in all years except 2015 (Figure 3).

Off DMV and SVA in the southern end of the Atlantic surfclam range, survey catches including both ocean quahog and Atlantic surfclam have become more common in recent years as Atlantic surfclam have shifted towards deeper water in response to warm water conditions (Weinberg 2005). This may change discard patterns in the future. It may be worth considering adjusting discard estimates for presumed discard mortality (currently 100%) if discarding ever rises to a level that substantially affects estimates of fishing mortality, as it is likely that some fraction of discarded Atlantic surfclam survive.

Bycatch and discard of Atlantic surfclam in other fisheries is near zero. Atlantic surfclam are not vulnerable to bottom trawls, gillnets or hook and line gear. They can be captured by scallop dredges, but the fisheries do not generally overlap in space, though that may change over time as Atlantic surfclam move to deeper water.

### Age and size at recruitment to the fishery

Age at recruitment to the Atlantic surfclam fishery depends on growth rates, which vary both spatially and temporally (see 1.3). The age at recruitment depends on the area being modeled (north vs. south), and the time period in question, as growth may change over time. Size at recruitment depends on the fishery selectivity estimated in the model. This issue is discussed in detail in section (1.4).

### Landings, fishing effort and prices

Landings and fishing effort data for 1982-2019 were from mandatory logbook reports (similar but more detailed than standard Vessel Trip Reports used in most other fisheries) with information on the location, duration, and landings of each trip. Data for earlier years were from Northeast Fisheries Science Center (2003) and Mid-Atlantic Fishery Management Council (2006).

Landings data from Atlantic surfclam logbooks are considered accurate in comparison to other fisheries because of the Individual Transferable Quota (ITQ) and cage tag systems. However, effort data are not reliable for 1981–1990 due to regulations that restricted the duration of fishing to 6 hours. Effort data are considered reliable for years before 1985 and after 1990.

Atlantic surfclam landings were mostly from the US Exclusive Economic Zone (EEZ) during 1965 to 2011 (Table 4 and Figure 4). EEZ landings peaked during 1973–1974 at about 33 thousand mt, and fell dramatically during the late 1970s and early 1980s before stabilizing beginning in about 1985. The ITQ system was implemented in 1990. EEZ landings were relatively stable and varied between 18 and 25 thousand mt during 1985 to 2019. Landings have not reached the quota of 26,218 mt since it was set in 2004 because of limited markets. The quotas are set at levels much lower than might be permitted under the FMP. Approximate state landings are shown in Table 4. Both New Jersey and New York have seen a sharp decline in Atlantic surfclam biomass within their state territorial waters over the past 20 years, and an accompanying drop in landings.

The bulk of EEZ landings were from the DMV region (Figure 2) during 1979-1980. After 1980, the bulk of landings were from the NJ region (Table 5 and Figure 5). Landings from LI were modest but began increasing in 2001. Landings from SNE were modest but increased starting in 2004. The high proportion of landings on GBK reflects the high catch rates there (see below).

Total fishing effort increased after 1990 and has been relatively high, but stable since 2007, particularly in the DMV and NJ regions (Table 6 and Figure 6). The bulk of the fishing effort was in areas where the majority of landings come from.

Real ex-vessel prices for the inshore and EEZ fisheries have been stable, since the mid-1990s (Table 7 and Figure 7). Nominal revenues for Atlantic surfclam during 2013 were about $33 million.

### Landings per unit effort (LPUE)

Nominal landings per unit effort (LPUE) based on logbook data was computed as total landings divided by total fishing effort for all vessels and all trips (Table 8 and Figure 8). Standardized LPUE was not estimated for this assessment because the data are not used analytically and because Northeast Fisheries Science Center (2007) showed that nominal and standardized trends were almost identical, when standardized trends were estimated in separate general linear models for each region with vessel and year effects.

Nominal LPUE has been declining steadily in SVA, DMV and NJ, which have recently been at or near record lows. LPUE in GBK and SNE have generally been high.

LPUE is not an ideal measure of fishable biomass trends for sessile and patchy stocks like Atlantic surfclam because fishermen target high density beds and change their operations to maintain relatively high catch rates as stock biomass declines (Hilborn et al. 1992).

### Spatial patterns in fishery data

Mean landings, fishing effort, and LPUE were calculated by ten-minute square (TNMS) from 1979-2019 in 5 year blocks (Figures 9 – 14). Only TNMS where more than ten bu of Atlantic surfclam were caught over the time period were included in maps. TNMS with reported landings less than 10 bu were probably in error, or from just a few exploratory tows. Inclusion of TNMS, with less than 10 bu distorted the graphical presentations because the area fished appeared unrealistically large.

Figures 9 – 14 show the spatial patterns of the Atlantic surfclam fishery over most of its history. In most blocks, the greatest concentration of fishing effort and landings occurred in the same thirty or so TNMS in the NJ region, with intermittent fishing activity in other regions and recent emphasis on SNE and GBK.

TNMS with the highest LPUE levels over time have been mostly in the NJ and DMV regions with irregular contributions from GBK and the Nantucket Shoals region of SNE.

### Important TNMS

TNMS important to the fishery were identified by choosing the 10 TNMS from with the highest mean landings during each 5 year time block. For example, a TNMS important during 1991-1995 could be selected regardless of its importance during earlier or later time periods. The list contains a subset of the total TNMS, because of overlap between the time periods and because the same TNMS tend to remain important. These plots are complicated by the "rule of three", which states that fine scale fishing location data cannot be shown for areas fished by three or fewer vessels due to confidentiality concerns. Trends in landings, effort, and LPUE were plotted (Figures 15 – 17) for each TNMS to show changes in conditions over time within individual TNMS.

With the exception of GBK, there are very few important ten-minute squares in which the LPUE has trended upwards in recent years, if they are still being fished. Most are currently at or below about 100 bushels per hour.

### Fishery length composition

Since 1982, port samplers have routinely collected shell length measurements from approximately 30 random landed Atlantic surfclam from selected fishing trips each year (Table 9).

Port sample length frequency data from the four regions show modest variation in size of landed Atlantic surfclam over time with declines in modal size in DMV and NJ since 2008 (Figures 18 – 24). Care should be taken in interpreting these due to small sample sizes in some cases (especially LI, SNE and GBK), but in general the data indicate that most landed Atlantic surfclam have been larger than 120mm SL. Commercial size distributions are discussed in detail in section (1.4).

### Fishery management

The Atlantic surfclam is managed by the Mid-Atlantic Fishery Management Council (Council). The Council is one of eight regional fishery management councils created when the United States (U.S.) Congress passed Public Law 94-265, the Magnuson Fishery Conservation And Management Act of 1976 (also known as Magnuson-Stevens Act or MSA). The law created a system of regional fisheries management designed to allow for regional, participatory governance. The Council develops fishery management plans and recommend management measures to the Secretary of Commerce through the National Marine Fisheries Service (NMFS) for its fisheries in the Exclusive Economic Zone of the U.S. (EEZ; 3-200 miles off the east coast). There are also fisheries for Atlantic surfclam in

New Jersey, New York, and Massachusetts within state waters (within 3 miles of shore); the state authorities are responsible for managing these fisheries.

Atlantic surfclam is managed with another species (Ocean quahog, *Arctica islandica*) under a single fishery management plan, that was first developed by the Council in 1977. The Atlantic surfclam fishery was initially managed through limited-entry restrictions, quarterly quotas, and fishing time restrictions. By the mid-1980s, effort limitation combined with overcapacity in the fishery meant that capacity utilization was very low, with vessels operating only 6 hours every other week in 1990. An individual transferrable quota (ITQ) system was established in 1990 which initially allocated shares to vessel owners based on a formula including historical catch and vessel size. Economic efficiency improved and management monitoring decreased as a result of initial ITQ implementation, but it also led to consolidation and displacement of labor (particularly non-vessel owning captains and crew). ITQ shares can be traded or leased to any non-foreign person or entity, with no pre-conditions of vessel ownership. Market consolidation and existing vertical integration have increased over time. From 1990 to 2005, the Atlantic surfclam fleet size decreased by about 70%.

Under the current management system, managers set an annual catch limit for Atlantic surfclam and allocate landings to the ITQ shares. The Council's annual catch limit recommendations for the upcoming fishing year(s) cannot exceed the acceptable biological catch (ABC) recommendation of its Scientific and Statistical Committee (SSC). The SSC serves as the Councils primary scientific/technical advisory body, and provides ongoing scientific advice for fishery management decisions, including recommendations for ABC, preventing overfishing, maximum sustainable yield, and achieving rebuilding targets.

In order to participate in the Atlantic surfclam fishery, fishermen must have a permit to commercially harvest and sell Atlantic surfclam (using valid ITQ shares), and there are mandatory reporting and vessel-monitoring requirements, as well as clam cage-tagging requirements. There is a minimum size for Atlantic surfclam, which can be suspended by managers if it is demonstrated the harvest of small Atlantic surfclam is below a certain threshold. Fishing areas can be closed due to environmental degradation or due to the toxins that cause paralytic shellfish poisoning (PSP). PSP is a public health concern for Atlantic surfclam. It is caused by saxitoxins, produced by the alga *Alexandrium fundyense* (red tide), that accumulate in shellfish, and has resulted in fishery closures in the Georges Bank Area of the EEZ. NMFS recently (2013) reopened portions of the closed areas to harvest of Atlantic surfclam for those vessels using a protocol for onboard screening and dockside testing to verify that clams harvested from these areas are safe. Areas can also be closed to Atlantic surfclam fishing if the abundance of small clams in an area meets certain threshold criteria. This small Atlantic surfclam closure provision was applied during the 1980's with three area closures (off Atlantic City, NJ, Ocean City, MD, and Chincoteague, VA), with the last of the three areas reopening in 1991.

### 1.3 TOR 2: Survey

#### Restratification of the NEFSC clam survey

The clam survey was restratified by an NEFSC sponsored working group in 2019 (Jacobson and Hennen 2019). The restratification resulted in a reduction in the total stock area, by concentrating the survey strata to the area that encompassed 99% of the historical stock density. Post stratification of historical survey data did not appreciably alter the rends in abundance, or the length composition of the survey (see Appendix 2). It did however change the scale of the swept area estimates of abundance somewhat, as both the density (n per tow) and stock area changed.

#### New Survey data

The restratification of the NEFSC clam survey also split the survey into two parts, such that each species is now surveyed separately. The survey focused on Atlantic surfclam in 2018 and 2019 and thus there is survey data collected under the new stratification included in this assessment. The descriptions of the survey data below are identical to those in (Northeast Fisheries Science Center 2017b) and are here for convenience only.

#### NEFSC clam surveys

Survey data used in this assessment were from 2 different sampling platforms. The first was the NEFSC clam surveys conducted during 1982–2011 by the *RV Delaware II* during summer (June–July), using a standard NEFSC survey hydraulic dredge with a submersible pump. The survey dredge had a 152 cm (60 in) blade and 5.08 cm (2 in) mesh liner to retain small individuals of the two target species (Atlantic surfclam and ocean quahogs). The survey dredge differed from commercial dredges because it was smaller (5 ft instead of 8-12.5 ft blade), had the small mesh liner, and because the pump was mounted on the dredge instead of the deck of the vessel. The survey dredge was useful for Atlantic surfclam as small as 50 mm SL (size selectivity described below). Changes in ship construction, winch design, winch speed and pump voltage that may have affected survey dredge efficiency were summarized in Table A7 of Northeast Fisheries Science Center (2003). The second survey platform was the *ESS Pursuit*, a commercial vessel that was contracted to conduct the NEFSC clam survey since 2012, when the *RV Delaware II* was retired. The *ESS Pursuit* used a modified commercial dredge described in detail in Hennen et al. (2016). Surveys conducted from the *ESS Pursuit* have taken place in August each year since 2012.

Surveys prior to 1982 were not used in this assessment because they were carried out during different seasons, used other sampling equipment or, in the case of 1981, have not been integrated into the clam survey database (Table A7 in (Northeast Fisheries Science Center 2003)).

NEFSC clam surveys were organized around NEFSC shellfish strata and stock assessment regions (Figure 2). Most Atlantic surfclam landings originate from areas covered by the survey. The survey did not cover GBK during 2005 and provided marginal coverage there in 1982, 1983, and 1984. Individual strata in other areas were sometimes missed. Strata and regions not sampled during a particular survey were "filled" for assessment purposes by borrowing data from the same stratum in the previous and/or next survey if these data were available (Table 32). Survey data were never borrowed from surveys before the previous, or beyond the next survey. A model–based imputation was investigated for the last assessment (Northeast Fisheries Science Center 2013), but the imputation tended to over–emphasize unsampled years and areas. Alternative approaches to imputing missing strata were not further pursued in this assessment.

Surveys followed a stratified random sampling design, allocating a pre-determined number of tows to each stratum. A standard tow was nominally 0.125 nm (232 m) in length (i.e. 5 minutes long at a speed of 1.5 knots) although sensor data used on surveys since 1997 show that tow distance increases with depth, varies between surveys and was typically longer than 0.125 nm (Weinberg et al. 2002). These problems were eliminated in 2012 when the survey was switched to the *ESS Pursuit*. For trend analysis, when using data from before 2012, changes in tow distance with depth were ignored and survey catches were adjusted to a standard tow distance of 1.5 nm based on ship's speed and start and stop times recorded on the bridge. Stations used to measure trends in Atlantic surfclam abundance were either random or "nearly" random. The few, nearly random tows were added in some previous surveys in a quasi–random fashion to ensure that important areas were sampled. Other non-random stations were occupied for a variety of purposes (e.g. selectivity experiments) but not used to estimate trends in abundance. Locations and catches of all stations in the survey have been mapped (Figures 25–33).

Occasionally, randomly selected stations were found to be too rocky or rough to tow, particularly on GBK. The proportion of random stations that could not be fished was an estimate of the proportion of habitat in an area that was not suitable habitat for Atlantic surfclam. These estimates were used in the calculation of Atlantic surfclam swept-area biomass (see below).

Following most survey tows, all Atlantic surfclam in the survey dredge are counted and shell length is measured to the nearest mm. Large catches were subsampled. Mean meat weight (kg) per tow was computed with shell length-meat weight (SLMW) equations (updated in this assessment) based on fresh meat weight samples obtained during the 1997–2019 surveys (see below).

### Survey tow distance and gear performance based on sensor data

Beginning with the 1997 survey, sensors were used to monitor depth (ambient pressure), differential pressure (the difference in pressure between the interior of the pump manifold and the ambient environment at fishing depth), x-tilt (port- starboard angle, or roll), y-tilt (fore-aft angle, or pitch) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor GPS position, vessel bearing and vessel speed. Most of the sensor data are averaged and recorded at 1 second intervals. These metrics of tow performance can be used to accurately gauge the true distance fished by the dredge.

### Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow (after 1997), was based on a measurement of the pitch of the dredge during each second of the tow. Pitch data were smoothed using a 7 second moving average and then compared to a "critical angle" to determine when the dredge was fishing effectively. When the dredge was above the critical angle it was assumed to be pitched too steeply for the blade to penetrate the sediment. When the dredge was pitched below the critical angle, it was assumed to be near enough to horizontal that the blade should penetrate and thus be actively fishing.

It is important to find a critical angle for tow distance that is neither too small, nor too large. When the dredge is bouncing over rough terrain it is unlikely to be fishing effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical angle is too small, many seconds when the dredge was actually fishing would be excluded, which would tend to bias estimates of tow distance down. Further discussion of the determination of critical angle as well as summaries of dredge performance by year are in appendices (7–9).

### NEFSC clam survey trends and composition data

NEFSC clam survey data for Atlantic surfclam, including the number and weight caught per tow were tabulated by year, region and for the entire stock (Table 11). Mean numbers per tow were used in the plots of trends because trends in mean kg per tow were similar. Approximate asymmetric 95% confidence intervals were based on the CV for stratified means and assume that the means were log normally distributed.

Survey trends for small Atlantic surfclam (Figure 34) provide some evidence for recruitment trends over time. Recruitment appears to be increasing the south, but declining in the north. Survey trends for fishable (120+mm) Atlantic surfclam (Figure 35) show evidence of decreasing abundance in the northern area and rough stability in the south. Based on survey data mapped to swept area abundance, biomass has been decreasing since the last assessment in 2011 in the north, but approximately stable in the south (Figure 36).

Survey age–length keys and stratified mean length composition data were used to estimate the age composition of Atlantic surfclam in NEFSC clam survey catches and the stock as a whole by year and region. Age composition was estimated for the years between 1982 and 2019 when surveys occurred. Ages ranged from 1-37 (Figures 37 – 43). Specific year classes and trends in length and age composition are discussed in the context of the assessment model (see 1.4).

Shell length composition data (Figures 44 – 49) can be helpful in visually identifying shifts in population demography. For example, there is evidence of recent recruitment in the southern area regions.

### Dredge efficiency

Changes to the NEFSC survey involved changes to the survey gear. In particular, shifting the survey dredge from the research dredge (RD) used on the *RV Delaware II* to the modified commercial dredge (MCD) used on the *ESS Pursuit* was an important modification in that it necessitated a re-evaluation of capture efficiency. Fortunately the MCD was the same dredge that was used in previous depletion experiments (Northeast Fisheries Science Center 2013) so estimates of capture efficiency already exist. These are discussed in detail in Appendix 3 and Northeast Fisheries Science Center (2013).

Estimates of survey dredge efficiency were used to generate prior distributions for capture efficiency for each survey in the assessment model (see 1.4). A comparison of the prior distribution for the RD to the prior distribution for the MCD shows that the MCD has higher and more precisely estimated efficiency (Figure 164).

### Size selectivity

Selectivity data were collected on the *ESS Pursuit* during selectivity experiments in 2008 – 2019. Data from the experiments were used to estimate size-selectivity for the MCD. The MCD was configured for survey operations, rather than commercial fishing operations. Thus, the size selectivity estimates for the commercial dredge used by the *ESS Pursuit* during cooperative survey work are not directly applicable to commercial catch data. Selectivity experiments are described in Hennen et al. (2016).

The data available for each selectivity study site included shell length data from: one MCD tow, and one F/V selectivity tow using either a commercial dredge lined with wire mesh or a specially designed selectivity dredge (SD). Gear testing work done in 2014 showed that the SD and the lined commercial dredge should be interchangeable in selectivity studies (Hennen et al. (2016)).

Shell length data from selectivity experiments conducted since the last assessment were tabulated using 1 mm shell length size groups (Tables 12 – 13). Survey size selectivity was estimated using data from 47 total sites.

Selectivity was modelled as a generalized additive mixed model (GAMM), where the shell length bin was a factor, predicting the binomial proportion of the survey catch over the total catch (SD + MCD). The fully saturated model was

$$P_L = e^{(\alpha + s(L) + s[YrSta, L] + offset)} \tag{1}$$

Where $P_L$ is the binomial proportion (logit link) estimated for shell length $L$ with intercept $\alpha$ and vector of model terms evaluated over $L$. The $s()$ terms indicate a spline over variables, in this case shell length ($L$) and a random effect (indicated with braces) due to station and year. The final term is an offset (Pinheiro and Bates (2006)) based on the tow distance at each station. Tow distance is a potential source of bias because clams can be unevenly distributed on the sea floor. The nominal time fished for the lined dredge is 45 s compared to 5 min. for a nominal survey tow, while the SD was towed for 2 min.

Using the GAMM methodology allowed greater flexibility in the model, when compared to assuming any particular shape. The basis dimension ($k$) in a spline determines the amount of “wiggle” allowed in the spline. Wood (2009)[2] suggests an objective method for choosing a basis dimension in splines. This method allows the data to determine the shape required to adequately fit them rather than the modeller.

[2]See R package mgcv documentation

The inclusion of random effects based on station is important because there is a great deal of variation in selectivity between stations. Variation across stations is essentially a nuisance parameter in our assessment because we are interested in the general selectivity over all possible stations, rather than the differences between them (Figure 51). Because we believe that clams taken from a particular place and time would tend to experience similar selectivity when compared to clams taken from a different place and time, it is appropriate to model selectivity using random effects.

Approximate confidence intervals were estimated using

$$CI_L = elogit^{(\rho_L \pm 1.96\sigma_L)} \tag{2}$$

Where $CI_L$ is the approximate confidence interval for selectivity at length $L$, $\rho_L$ is the corresponding logit scale model estimate, $\sigma_L$ is the standard error and elogit is the inverse of the logit function.

Selectivity estimates (Tables 14 – 15; Figure 52) were used to generate swept area and survey index plots (Figures 34 – 36) and are useful for comparison to assessment model results.

### Shell length, meat weight relationships

The shell length-meat weight (SLMW) relationships are important because they are used to convert numbers of Atlantic surfclam in survey catches to meat weight equivalents. The survey meat weight equivalents are inputs in the stock assessment models used to estimate stock biomass, which is reported in units of meat weight. Meat weights for Atlantic surfclam include all of the soft tissues within the shell. All meat weights greater than 0.5 kg were assumed to be data entry error, and were removed from the analysis.

Generalized linear mixed models (GLMM; Venables and Dichmont (2004)) were used to predict clam meat weight, using equations of the form:

$$MW = e^{(\alpha + \beta_0 ln(L) + \beta_1 c_1 + \beta_2 c_2 + \cdots + \beta_n c_n)} \tag{3}$$

where $MW$ was meat weight, $L$ was shell length, $c_1, \cdots, c_n$ were covariate predictors (*e.g.*, region or depth), and $\alpha$ and $\beta_i$ were the estimated parameters. Examination of the variance of the weights as a function of shell length indicated that weight increased approximately linearly with shell height, implying that the Poisson family was reasonable for the distributions of meat weights (McCullagh and Nelder 1989). The GLMM in all analyses used the quasi-Poisson family with a log link. Quasi-Poisson is a Poisson distribution with a variance inflation parameter that relaxes the Poisson requirement that the mean must equal the variance. Because shell length to meat weight relationships for Atlantic surfclam at the same station are likely to be more similar than those at other stations, we considered the sampling station as a grouping factor ("random effect") in the analysis.

Models with fixed effects for year and region (Table 16) were fit to the data and compared. The best model by AIC and BIC was a model with fixed effects for shell length, depth, and region and random effects for shell length slope and the intercept, using both the year and the station as the grouping variables.

Regional differences in meat weight are meaningful, particularly for the largest animals (Figure 53), though some of the differences between regions can be explained by the different depths found there (Figure 54).

## Age and growth

Atlantic surfclam were measured at sea and the shells were retained for ageing in the laboratory. Shells for ageing were collected based on a length stratified sampling plan. A recent study confirmed that rings on shells collected during the summer clam survey are annuli that can be used to estimate age (Northeast Fisheries Science Center 2010). Age and length samples are available for most regions, but not from every survey (Table 16).

Plots of age vs. shell length by year and region (Figures 55 – 61) indicate that growth patterns have been relatively constant in most regions over time with DMV and NJ, where growth has slowed and maximum size has decreased over the last two decades.

Von Bertalanffy parameters for growth in shell length were estimated for each region and each survey year for which sufficient data existed (Table 17). The Von Bertalanffy growth curve used in the calculations was:

$$L_a = L_\infty(1 - e^{(-k(a-t_0))}) \tag{4}$$

Where $L_a$ was length (mm) at age $a$, and $L_\infty$, $k$ and $t_0$ are Von Bertalanffy parameters.

Atlantic surfclam are thought to mature very early. Data are limited but Atlantic surfclam off New Jersey may reach maturity as early as 3 months after settlement and at lengths of less than 5 mm (Chintala and Grassle 1995; Chintala 1997).

## Depth and temperature

As ocean temperatures increase, the distribution and biology of Atlantic surfclam are potentially changing with potential effects on fishery productivity. For example, increasing water temperature may result in changes to the biological parameters that describe growth (Munroe et al. 2016). Increasing water temperature may also be driving a shift in Atlantic surfclam distribution, to deeper water in the southern area (Weinberg et al. 2002). It is reasonable to assume that any responses to temperature would be strongest in the southern-most regions (SVA, DMV and NJ), where ocean temperatures are warmest and probably nearest the warm water tolerance for Atlantic surfclam.

Survey stations are distributed randomly relative to depth within a stratum and the same strata tend to be sampled over time within a region (Table 32). Therefore, if the depth distribution of Atlantic surfclam were trending over time, the depth at which most of the animals were caught within a region might be expected to increase. Plots of the depth at which the median cumulative catch within each region occurs over time show this relationship in two regions, DMV and NJ (Figures **??** – 63).

Temperature was recorded as part of the survey station data (beginning in 2002), and may be a useful indicator of habitat preference for Atlantic surfclam. Plots of the temperature and depth recorded at each survey station over time, against the total number of Atlantic surfclam caught are provided here (Figures **??** – 65). The results indicate that temperature and depth preferences vary by region, but appear to be relatively consistent over (recent) time. This may be indicative of local adaptation, or there may be other local factors, potentially correlated with temperature and depth, that influence habitat preference in each region.

### Changes in biological parameters

If increasing ocean temperature negatively affects the fitness of Atlantic surfclam, one might expect to see decreases in the biological parameters that describe growth, particularly in the southernmost regions where water temperatures are highest. Analysis indicates that DMV and NJ have experienced declines in average maximum length ($L_\infty$) through time (Figure 66). NJ and SNE have shown decreases in the rate at which an animal approaches its theoretical maximum size ($K$; Figure 67).

## 1.4 TOR 3: Model

The Atlantic surfclam assessment model was implemented in SS3[3] (Methot and Wetzel 2013). In the last benchmark, separate SS3 models were developed for Atlantic surfclam in the southern and northern areas. SS, however, allows for spatially separable model estimates, which allowed for a single model utilizing a division of the stock into two areas, the north and the south. Differences in availability of survey data and divergent population dynamics including different biomass and mortality trends, changes in proportion of total biomass in the two areas over time, and very limited fishing in the north drove the decision to use a spatial model. The combined spatial model is preferred over two entirely separate models because producing results from a single model is far less complex than combining results from two entirely separate models.

Empirical assessment calculations that did not involve assessment models were also included for comparison (Appendix 5). Together the two approaches form a complementary set that lead to the same conclusions for the Atlantic surfclam stock.

### Configuration

Survey trend data were split into three series for each area. The first is the RDtrend series which covers the entire RD time series and is based on numbers per $m^2$ using vessel speed and start/stop times as explained in Section 1.3. The second series is RDscale, which was based on numbers per tow using the more precise sensor tow distances. RDscale was used to fit the catchability parameter for RDscale, but did not inform trend (it was turned off in the likelihood). RDscale was available from 1997 till the end of the RD time series. The third series was MCD which used sensor distances and informed both scale (its own catchability parameter) and trend, but was available only for the period of the MCD survey (3 years for each area, see Figure 68).

Fishery and survey selectivity were functions of size rather than age in SS3 models. Conditional age at length data, rather than traditional age composition data, were used in fitting models. The conditional age vector with indices $t$, $a$, $L$ for example, gives the proportion or number of observed ages ($a$) from samples of length $L$ in year $t$ of the NEFSC clam survey. The major advantage of the conditional approach is that more information about growth (including variance in size at age) and year-class strength is preserved. Size composition data are not used twice (once as size composition data and once in calculation of traditional catch at age). Finally, the sampling distribution of conditional age data is probably easier and more accurately characterized as a multinomial, conditional on the number of ages (at $t$ and $L$) actually sampled.

The same types of data (Figure 68) were available for both areas, although more precise and numerous data were available for the southern area. The additional data for the south made it possible to estimate additional selectivity parameters, as well as biomass and mortality over a longer time period (Tables 20 – 21). It was necessary to fix two selectivity parameter parameter estimates in modelling Atlantic surfclam in the north because data were so limited and catches were nearly zero over much of the time series.

[3]Stock Synthesis Model version SS-V3.30.14 compiled for 64-bit linux.

Dome shaped survey selectivity curves with parameters were used in SS3 models for for all survels (Figure 73). Field estimates suggested domed selectivity was appropriate. Field estimates were relatively precise, based on a great deal of data, and were obtained from designed experiments carried out in association with the stratified random survey using actual survey sampling gear (Figure 52; Northeast Fisheries Science Center (2013)). Additionally, in SS dome shaped selectivity are flexible enough to become flat-topped if the fit to the data suggest it.

The number of trips sampled by port agents was used as initial effective sample sizes for fishery length data in each year. The number of survey tows that caught Atlantic surfclam was used as initial effective sample size for survey size composition data in each year. The number of fish aged in each size group and year was used as the initial effective sample size for survey conditional catch at age data. Initial log scale standard deviations for survey abundance trend data were derived from the CV for mean numbers per tow in each year (and assumed that errors were lognormal). These initial specifications for length and age data were "tuned" (adjusted up or down) based on preliminary model fits by multiplying the values for each type of data by a constant based on the recommendations of (Francis 2011). The initial standard deviations for survey trend data were tuned, if necessary, based on preliminary model fits by adding a constant to the standard deviation for each observation in the time series (Francis 2011).

The proportion of total recruitment (estimated as annual deviations from the stock recruitment relationship) that ended up in each each area was allowed to vary over time by linking recruitment to a random walk process in the proportion recruited to each area with annual time steps. Animals were not allowed to move from one area to the other in the model.

The last benchmark model produced an unusual estimate of growth for the southern area in which the CV at maximum age (somewhat analogous to the CV of $L_\infty$) was less than the CV at younger ages (Figure 69). This result suggested that the largest animals were not the oldest animals, which while possible, produced some consternation among reviewers (see section 1.7). For this management track assessment, growth in the south was allowed to vary with time by estimating a trend in $L_\infty$ through time (Figures 70 - 71).

Other important changes from the benchmark assessment are detailed in Appendix (4).

### Priors for survey dredge capture efficiency

The prior distributions for survey dredge capture efficiencies were important because the models are not otherwise strongly informed regarding scale. The last Atlantic surfclam assessment (Northeast Fisheries Science Center 2013) details the work that was done to estimate a prior for the distribution of capture efficiency for the research dredge (RD) last used in 2011. Appendix 3 details the work done to estimate a prior for the distribution of the modified commercial dredge (MCD) used since 2011.

Issues

Other potential issues are the use of assumed parameter values for $M$, steepness and some selectivity parameters for RDtrendN. The $M$ value used was based on observed longevity. There was no experimental basis for the assumed steepness ($h = 0.95$) used in the assessment model as there were no observations of recruitment at low stock size available (although some may be available soon in the north). The $h$ used was high and resulted in no apparent relationship between spawning biomass and recruitment. Sensitivities testing each of these assumptions are described in section 1.4. The model was unable to completely estimate selectivity for the RDtrend survey in the north due to highly variable length composition data through time. It is possible that some of the lack of fit could be alleviated using time varying selectivity. The gear used for the RDtrend survey was consistent through time however, and it seems more likely that the lack of fit can be explained by observation error. For example none of the data in the early part of time series for the north is fit particularly well by the model and it has relatively low associated precision (small sample size). Another possible avenue to improve the fit would be to attempt to estimate time varying growth in the north, as was done in the south. There is evidence, however of changes in $L_\infty$ and $k$ over time (see section 1.3) in the south, but not in the north and this approach was not pursued.

The survey index for the north in the early part of the time series is not fit well. The early part of the time series is uncertain relative to trend because the survey index increased rapidly in the absence of any prior fishery removals that would have accounted for the population being in a depleted state (where the increase would represent recovery). There is no support for a low biomass in the early part of the time series in the composition data either. With no mechanism to explain the increase from 1984 to 1995 (or more precisely the low biomass in 1984), the model does not believe the survey. The composition for the early years in the north are not fit well by the model either. In part this is due to the low weights put on those data, based on few observations. Fitting those data tightly at the expensive of more precise data later in the time series would not be advisable. Sensitivities removing the uncertain data associated with the early part of the time series in the north are discussed in section 1.4.

The base model has some poorly determined parameters (Table 22). In general these were recruitment deviations (recdev), deviations in the apportionment of recruits to each area (parm_dev) or selectivity parameters (selparm). The recruitment related parameters are expected to be difficult to determine because little of the data directly measures recruitment. None of the gear used for survey or commercial data selects for young animals and the variation in size at age is large enough to make the length composition data poor for estimation of recruitment deviations. That leaves only the age at length composition data, which is not collected in the fishery. The poorly determined selectivity parameters are the components of the double normal curve that determine the starting and ending elevations of the curve. These were fixed in previous assessments and were estimated here with strong penalties. The components of the double normal are difficult to estimate because they describe areas of the selectivity curve that are typically near zero and therefore by definition are based on few data. It may be worth exploring alternative parameterizations for selectivity curves in future assessments.

The models solution for $Q$ (the constant of proportionality between the observed index and the operational model abundance) for the RDscale index in the north was far from the mean of the prior distribution associated with it (Figure 72). It was in fact considerably higher, and higher than the $Q$ for the RDscale index in the south, implying that the survey in the north was much more efficient than the survey in the south. This is unlikely as the fishing conditions in the north are generally much more difficult. It is important to remember however that $Q$ is not strictly interpretable as a measure of gear efficiency. The model $Q$ can be an alias for many things in a complex model and is more directly interpreted as an internal scaling factor between the disparate components of the model. In this case the model had to make sense of the fact that in the northern area, an apparently large population (based on the high RDtrend index) was fished down very quickly (based on the low MCD estimates) with a modest set of removals. This implies that the abundance could not have been as high as the combination of the RDscale index and its $Q$ prior indicate. The model must therefore believe either the MCD index (a much more precise estimate) or the RDscale index, but not both. The model chooses to trust the MCD index.

### Fit and estimates from basecase models

The biological parameters used in the assessment model were based on experimentally derived values (Figures 74 – 76). Selectivity was estimated and retained the domed shape seen in the last assessment (Figure 73). The fit to the surveys was acceptable and the residuals generally did not show trends or high variance (Figures 77 – 81). The fit to RDtrendN is not without flaws, as discussed above, but forcing the model to fit that survey better was detrimental to the fits to other (and more reliable) data. The fit to the composition data was generally tight (Figures 82 – 107). Data weighting decisions are shown in Figure 108. Model time series results are shown in Figure 109 and parameter estimates are shown in Table 21.

Calculating $F$ for the whole stock can be difficult if more than 1 area, fleet and selectivity are involved. In this case the true $F$ for each area, which is a model output was averaged across the areas after being weighted by the fully selected number of animals in each area.

$$F_{Whole} = \frac{N_S}{N_S + N_N} F_S + \frac{N_N}{N_S + N_N} F_N \tag{5}$$

In this case $N_S$ is the fully selected number of animals in the southern area and $N_N$ is the fully selected number of animals in the north.

### Likelihood profile analysis

Likelihood profile analysis of the model consisted of fixing the unfished recruitment parameter ($R_0$) at successive values that bracketed the $R_0$ solution (from the base case model) and estimating all of the other parameters in the model.

Likelihood profile results indicate that goodness of fit for the priors on survey catchability were best near the basecase model run (Table 23 and Figure 110). Survey age data support higher $R_0$ (higher biomass) and length composition data lower $R_0$ (lower biomass). However, the differences in total likelihood were small (Table 23). The one area of data conflict that appears to make a substantial difference in total likelihood is between the parameter prior distributions (on survey catchability), which prefers the solution, and the age composition data, which prefer a lower values of $R_0$.

### Sensitivities

Experimental model runs testing the effects of model manipulations (for example with either extra parameters or fewer sources of data) were informative.

The unusual growth pattern observed in the last assessment (Figure 69) was initially addressed through sensitivity testing by forcing the CV around average maximum length ($L_\infty$, or in SS terms CVold) to match the CV at minimum age (the age below which SS interpolates a straight line to age 0, rather than the Von Bertalanffy growth curve; Figure 111). This resulted in a reduction in the fit to length composition data and did not have a substantive affect on the scale or trend in abundance, F or recruitment (Figure 112 - 113).

The stock recruitment relationship in Atlantic surfclam has proved difficult to model Timbs et al. (2018) in large part due to the fact that a low abundance has never been observed. The abundance in the northern area may now be sufficiently low to generate some data to fill in the left side of the stock recruit curve, although current recruitment will not be evident to the survey for a few more years due to selectivity. The stock recruitment relationship has the potential to affect reference point calculations and can be relevant to projections. A model run with a low steepness ($h = 0.4$) was tested in sensitivity. Lowering steepness did not affect the estimates of abundance or the trend in abundance in the model through the current year (Figure 112); it's affect on the projections is discussed in Section 1.4.

The early years in the survey time series for the northern area are problematic. They are based on relatively few observations and may be spatially biased (see Appendix 5). They affect the reference point calculation in that they exert relatively high influence on the models determination of it's presumptive unfished state, based on temporal proximity. A model run without survey data prior to 1992 for the north was tested in sensitivity. It did not have a strong affect on the trend or scale of abundance (Figure 112).

Similarly, the composition data from the fishery in the north is questionable because it is based on few observations and produces unusual distributions that are difficult to explain with standard selectivity curves. A model run without commercial data prior to 1992 for the north was tested in sensitivity. It did not have a strong affect on the trend or scale of abundance (Figure 112).

Allowing the Von Bertalanffy $K$ parameter to vary through time along with $L_\infty$ had little affect on the scale, trend or fit to the data and the simpler model (constant $K$) was preferred for parsimony.

### Internal retrospective

A seven year retrospective analysis was attempted, but only 6 years worth of peels converged. Dropping the seventh year meant that no MCD survey data was available for the northern area, which caused difficulty for the model as it was attempting to fit selectivity curves for that survey with no data. Previous retrospective analyses used fixed selectivity and growth parameters for the northern area, which allowed for peels in which a survey index was dropped. Rather than attempt to change the model to fixed values, the retrospective analysis shown here stops after 6 peels. Future retrospective analyses should allow for seven year peels as data from additional survey years are added to the model.

The retrospective plots of biomass (Figure 114), $F$ (Figure 115) and recruitment (Figure 116) show modest divergence from the current solution as years of data were dropped. The divergence does not indicate directional bias and the Mohn's $\rho$ values for $F$ and SSB (-0.376 and 0.144, respectively) are considered "minor" as applying the retrospective correction would not shift the terminal estimates of SSB and F outside the 90% confidence interval associated with each.

### Historical retrospective

The estimated whole stock biomass in this assessment is lower in scale than previous assessments (Figure 117). The scale shift over time reflects the difficulty in determining scale in the Atlantic surfclam assessment, progress as priors for catchability were developed, and is typical of a low $F$ fishery.

### MCMC

Markov chain Monte Carlo (MCMC) runs were used as a diagnostic to insure that the approximate uncertainty intervals based on the likelihood surface were appropriate. One million MCMC iterations from which one in every thousand were kept were used to generate posterior distributions for some parameters of interest. These were compared to random normal distributions generated using the parameter estimates (as the mean) and approximate standard deviation from the likelihood surface. The median, fifth and $95^{th}$ quantiles from the posterior distributions and likelihood based uncertainty distributions were similar (Figure 118).

### Sensitivity to starting conditions

The initial parameter values were jittered in a series of diagnostic model runs. The jitter process in SS has been recently modified to sample from a normal distribution that distributes its probability mass between the minimum and maximum values for each parameter. This tended to produce some large departures from the initial values used in the base run of this assessment model and many of the jitter runs did not converge. In future iterations of the Atlantic surfclam assessment, min and max parameter values should be considered carefully with this diagnostic in mind.

Based on the converged jitter runs, the Atlantic surfclam model does show some sensitivity to initial conditions. In particular, and perhaps not unexpectedly, the scale of abundance appears sensitive (Figure 119). The trend in biomass and specifically the proportion of current biomass to initial biomass indicate that the relative status of the stock is not sensitive to starting conditions.

### Current reference points

The current biological reference points for Atlantic surfclam are described in detail in Northeast Fisheries Science Center (2017a). The biomass reference point is straightforward

$$SSB_{Threshold} = \frac{SSB_0}{4}$$

where $SSB_0$ is derived from the base model run. The fishing mortality threshold is more complicated and derived from a management strategy evaluation described in Northeast Fisheries Science Center (2017a); Hennen et al. (2018). The recommendation $F_{Threshold} = 0.12$ from the MSE has an important implementation problem given that estimated fishing mortality rates are uncertain due to uncertainty in the scale of the biomass estimates in previous assessments. Thus, it would be very difficult to reliably compare an estimated fishing mortality rate to $F_{Threshold}$ and determine if overfishing is occurring. The assessment working group concluded it would be better to employ an $F_{Threshold}$ reference point based on trends using the average fishing mortality rate between 1982 and 2015 (the period for which survey data existed for the assessment in which the reference point was developed).

$$E_{y=1982}^{2015}[F_y] = F^*$$

The catch during that time period did not appear to result in overfishing. There was no evidence of overfishing in the age/size compositions and biomass estimates were near $SSB_0$ (see 1.4 and 5). The highest average fishing mortality between 1982 and 2015 for the southern area in sensitivity analyses was $F^*_{Max} = 0.03$. There is a high probability that $\frac{F_{MSY}}{F^*} > 4$ because

$$\frac{F_{MSY}}{F^*_{Max}} = \frac{0.12}{0.03} = 4$$

and $F^*_{Max}$ was taken from the sensitivity run with the lowest biomass and thus highest $F$ of any model run for the southern area. In addition, catch curve total mortality $(F + M)$ estimates for the southern area during this time period averaged 0.14, compared to the assumed $M$ of 0.15. Empirical exploitation rates $< 0.05$, provided further evidence that $F$ was low **?**. Thus any $F^*$ calculated from another model run would likely be lower than $F^*_{Max}$.

The recommended fishing mortality reference point was

$$F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$$

rather than a specific rate such as 0.12. It is important that $F^*$ be calculated using the period between 1982 and 2015 in this, and in future assessments, as that was a period during which overfishing was very unlikely. Allowing the years that compose the reference point to shift over time would allow the reference point to normalize to current behavior. That is, the reference point would decrease during a regime of less fishing pressure and increase during a regime of more fishing pressure, which is not a desirable characteristic for a reference point.

There are three primary advantages to this recommendation. First, the status ratio used to identify overfishing

$$\frac{F_y}{F_{Threshold}} = \frac{F_y}{F^* \frac{F_{MSY}}{F^*_{Max}}}$$

provides information about relative exploitation rates that is not available in the ratio $\frac{F_y}{0.12}$ given the high degree of certainty in estimated trends and high degree of uncertainty in the scale of biomass estimates. Second, the recommended reference point is robust because it will adjust to changes in the scale of Atlantic surfclam biomass estimates, which can be expected in future assessments, at least over the short term. Finally, the scaling factor $\frac{F_{MSY}}{F^*_{Max}}$ can be re-examined and/or replaced as biomass estimates improve.

Table 1: Biological reference points for Atlantic surfclam.

| Reference point | Value |
|---|---|
| $F_{MSY} = F_{Theshold}$ | $F^* \frac{F_{MSY}}{F^*_{Max}}$ |
| $K$ | $SSB_0$ |
| $SSB_{MSY} = SSB_{Target}$ | $\frac{SSB_0}{2}$ |
| $\frac{SSB_{MSY}}{2} = SSB_{Threshold}$ | $\frac{SSB_0}{4}$ |

### 1.5 TOR 4: Stock status

***Previous assessment***

The assessment model was configured differently from the base model in the last assessment (Northeast Fisheries Science Center 2017a). The most important change was a conversion from two models with one area each, to a single model with two areas. Therefore, the previous assessment model cannot be directly compared to the model used in the current assessment, though a reasonable effort has been made to do so in (Appendix 4). It is, however, possible to compare the current assessment estimates of biomass and fishing mortality to the current and recommended biological reference points.

***Current reference points***

Comparing the terminal biomass ($B_{2019}$) and fishing mortality estimates ($F_{2019}$) to the current reference points (Table 1) shows a low probability of either overfishing or overfished status for the Atlantic surfclam stock in the US EEZ. The method for deriving reference points has not changed, but the model has. This results in new (recommended) reference points in this assessment.

***Recommended reference points***

The recommended reference points are an update of the existing method using the new model. There is a low probability that the Atlantic surfclam stock in the US EEZ is experiencing overfishing ($F_{2019} < F_{Threshold}$; Table 25; Figure 160–161), and there is a low probability that the Atlantic surfclam stock in the US EEZ is overfished ($B_{2019} < B_{Threshold}$; Table 26; Figure 160 and 162). According to the recommended reference point definitions, the Atlantic surfclam stock is not overfished and overfishing is not occurring.

### 1.6 TOR 5: Projections

Basecase models were used to project biomass of Atlantic surfclam, catch (mt), and fully selected fishing mortality in both areas, and in the combined stock during 2020-2026 (Tables 27 - 28 and Figure 123). Three harvest policies were assumed: 1) $F = F_{Threshold} = F_{OFL}$ ($F$ at the OFL), 2) status quo catch (19255 mt) and 3) the maximum allowed catch under the current FMP or "quota level" catch (29364 mt) in the combined areas. Results indicate that biomass will remain higher than the biomass threshold and projected fishing mortality levels will be lower than the fishing mortality threshold for the entire resource.

Projection calculations were carried out in SS3 for the whole stock using the basecase model. Thus, the distribution of catches, relative growth rates, etc., were the same as in the terminal year of the base case model. Catches were landings multiplied by 1.12 to account for assumed 12% incidental mortality. Catches during 2020 were assumed the same as during 2019. For lack of better information, catches in the northern area during 2020-2026 were assumed to be the same proportion of the total catch as in the terminal year catch. This assumption is likely reasonable for the first few years because of processor infrastructure and fleet range limitations.

It is unlikely that the stock will be overfished within the next six years. The maximum probability of overfished status coincides with the minimum biomass estimate over the six year time horizon. The distributions of $SSB_y$ and $SSB_{Threshold}$ were assumed log normal with means equal to their respective point estimates and variances equal to their delta method variances. One million draws from possible threshold values were drawn from correlated distributions with means and variances as described above, where the correlation between them was equal to the correlation between $SSB_y$ and $SSB_{Threshold}$ estimated in the model. Each pair of draws was compared. Overfished status occurred when the threshold draw was greater than the biomass draw. Probabilities were equal to the number of overfished occurrences divided by the number of comparisons made (Shertzer et al. 2008). The probability of the whole stock being overfished was low for all projection scenarios considered (Figure 125).

The most likely fishing scenario is probably status quo catch, because the fishery is market limited and has been catching less than the quota since 2004 (Table 4). The quota scenario with higher catches was therefore a reasonable upper bound on likely fishing pressure over the next ten years. Using the quota scenario, the maximum probability of being overfished in any one year in next five ($P^*$) was low (Figure 125) and the cumulative probability of being overfished at any time during the next ten years ($1 - \prod_y \{1 - p_y^*\}$) (Table 29), where $p_y^*$ is the $P^*$ value for each year was also low (see Shertzer et al. (2008)).

Projected fishing mortality levels are lower than the fishing mortality threshold for the entire resource under all scenarios except $F = F_{OFL}$ for each of the stock areas (Figure 126; Table 28). The cumulative probability of experiencing overfishing using the status quo catch or quota scenarios in any of the projection years was also low (Table 29).

Probability distributions of the catch at the OFL were generated by repeated draws from a lognormal distribution of catch in each year, with a mean equal to the point estimate of the catch and a cv equal to the model estimated cv for each catch value (Figure 127; Table 30).

### 1.7 TOR 6: Comments From Previous Review Panel

The panel comments here come from the SAW 61 panel summary report. Comments from the panel are in italicized text and the responses are in plain text.

*1. It was stated several times, both in the report and during the plenary sessions, that commercial landings are thought to be very accurate. However, data on landings arise exclusively from skippers' logbooks, and the Panel expressed concern that the reported landings have never been subject to verification by outside sources. Given this, the Panel found that the actual quality of the landings data is impossible to assess.*

Landings are still assumed to be very accurate (cv=0.01). This might be investigated in a future assessment. Particularly if the certainty around estimated scale increases, which might allow the model to converge without firm estimates of catch.

*2. ... discarding is assumed to be zero in recent years (following a period of discarding driven by now-defunct minimum landing sizes)... An onboard observer programme has now been initiated by NEFSC, and this should provide confidence for future assessments that the discard rate is indeed very low (or zero)...*

Discards were explicitly included in this assessment (see 1.2).

*3. The Panel was informed that surfclam cage tags are valid across the entire area and can be transferred up and down the coast, so that even localized depletion will not result in quotas being exhausted. This implies that the quota cannot prevent localized depletion.*

This remains true but is a management concern.

*4. A fixed incidental mortality rate of 12% is applied to all landings. This is based on theoretical analysis, and is intended to account for clams which are damaged by the passage of the dredge while not being caught. The Panel raised a number of concerns regarding this assumption:*

*a. It is not clear whether incidental mortality is applied to the historical discards included in the assessment. We assume that discards die, but the Panel considers that the incidental mortality rate should be applied to total catch (rather than just landings).*

*b. How strong is the basis of the indirect mortality value (12%)? Is it size-based? Is it important to retain it in the assessment? One could argue that if it is fixed through time, and not size-based, then it simply scales the assessment and does not modify the advice  particular if said advice is largely trend-based (as we discuss further below), and when fishing mortality rates are so low.*

This issue was not examined in this assessment. Data on clappers (hinge articulated but no animal present, which indicates relatively recent mortality) is collected on surveys, but that data is considered a poor index of mortality in Atlantic surfclam. The gear used to capture and sort Atlantic surfclam on the survey is hard on shells and probably disarticulates most clapper shells. This has not however, been formally evaluated and is a possible consideration for future research.

*5. The Panel noted that there was uncertainty in the meat-weight conversion function used, due to size distribution of the catch and the season of harvest. In future assessments, it would be appropriate to attempt to address this issue, if possible.*

The conversion from volume caught to meat weight is a source of uncertainty in the catch and could be included in the input cv of catch in the model (see panel comment 1 above). Previous assessment models did not converge when catch was uncertain and increasing the cv around catch was not tested in this assessment. Future assessments should consider attempting this. The size distribution of the catch can be interpolated from the length composition of the catch used in the assessment. Seasonal meat weight data for Atlantic surfclam has not been collected outside of industry (for whom it is considered proprietary) and is unlikely to be available for future assessments either without new research.

*6. …The working group used a data "borrowing" strategy to fill gaps where strata or regions have not been surveyed in particular years. This involves borrowing, without adjustment, both abundance and composition data from adjacent years for the same stratum or region… The panel accepts that this is unlikely to have caused biases in the assessment, particularly since the area for which borrowing is used tends to be relatively small, but strongly urges the working group to determine a statistical approach to imputation, e.g. based on GLM/GAMs or geostatistical methods such as kriging.*

The problem caused by borrowing has been much reduced through restratification of the NEFSC clam survey (see 1.3).

*7. The working group showed evidence that surfclam are shifting into deeper waters in the southern part of its range, this probably being a response to increased water temperatures. Increased spatial overlap between Atlantic surfclam and ocean quahog habitat is an expected consequence of this shift, and this was also demonstrated in the survey data. The working group also demonstrated changes in regional growth patterns over time, which may be attributable to increased ocean temperature. It will be important to examine the drivers of these changes and the implications for stock productivity. Interpretation of trends in von Bertalanffy growth parameters $K$ and $L_\infty$ is problematic, given their likely strong negative correlation. The panel recommends examination of trends in growth performance indices that combine information from both these parameters.*

The changes in growth over time were explicitly estimated in this assessment (see 1.4). Shifting habitat was addressed through the restratification of the survey (see 1.3).

*8. The panel felt that insufficient detail was provided in the report on the process that led to the working group accepting base models for each area (these have labels of BASE7 and GBKBASE7, suggesting that several iterations had occurred)…*

Additional detail regarding the development of the base model has been included in this report (see Appendix 4).

*9. The panel noted the following issues with the assessment model or data inputs:*

1. *Catch is assumed to be known without error. This could introduce bias if some catch is underreported or if discarding or reporting patterns change over time;*

   This has been discussed above.

2. *Non-random allocation of some or all tows within surveys is likely to lead to bias in indices, especially if such non-random allocation is focused on areas thought to be important for the fishery, and should be avoided. Random, probabilistic sampling should be used;*

   Sampling is random within surveys.

3. *The priors for catchability were estimated differently for the old and new surveys; in general the depletion methodology was thought to be better but the implementation may be biased and could be improved;*

   Depletion studies using the old survey gear cannot be improved because the vessel and gear have been retired from service. Also this was attempted in 1997 but the gear was so inefficient that the sites were never depleted.

4. *Catchability for the survey in the model may not be precisely the same as assumed by the prior; in particular, if significant parts of the fishery are not included in the survey area (e.g., Nantucket Shoals);*

   The prior distributions for catchability are sufficiently diffuse that almost any value will not cause convergence issues. If the data suggest a solution for catchability that is unlikely given the prior, the model will tend to follow the data. This is evident based on the results for catchability on the RDtrendN survey in this assessment (Figure 72).

5. *The assumed dome-shaped selectivity patterns for the survey were based on gear selectivity experiments and are not identical to the way selectivity is defined in the model; the commercial selectivity pattern was not reflective of the experimentally-estimated gear selectivity because large individuals are not fully selected by the fishery. The cause of this is probably fishery behavior, especially the choice of areas to be fished;*

   Agreed. The selectivity patterns used in the assessment model are sufficiently flexible to accommodate a number of potential shapes, including flat-topped selectivity.

6. *The distribution of size-at-age in the assessment has the largest individuals at intermediate ages (probably because the CVs on size at age for the older ages are too small). This may cause a bias in the model estimates of F;*

   Some effort was spent on fixing this issue in this assessment (see 1.4). Growth is now fully estimated and the problem is less severe than it was. The fact remains however that the largest individuals are not necessarily the oldest individuals in the data. This has some reasonable biological explanations, in that the largest individuals are likely to be the most vulnerable to mortality due to high temperature Narváez et al. (2015). Therefore the largest individuals have a shorter life expectancy than smaller animals.

7. *Ages for the conditional age compositions appear to be reliably estimated based on both the repeatability of ageing and marginal increment analysis; and*

8. *There were conflicts between priors and some other data sets for both models, but especially that for the Southern Area. This is a common problem in integrated stock assessments but may be indicative of structural problems that could be explored (e.g., un-modelled heterogeneity in growth, recruitment, or mortality).*

   The growth aspect of this comment was addressed in this assessment. The conflicts between priors and other data sources appear to be less than they were (Figure 110).

*10. The panel agreed that following additional work or documentation would have been useful for this assessment:*

1. *Markov chain Monte Carlo (MCMC) runs to characterize uncertainty; these can be particularly useful for describing uncertainty in derived quantities like SSB/SSBThreshold and can also provide powerful diagnostic tools, especially to identify poorly-determined parameters and structural problems; an MCMC run at least for the two base cases would have been very helpful;*

   MCMC were run for comparison to the Hessian based estimates of uncertainty. The results were not substantively different.

2. *The rate of natural mortality, M, is assumed and fixed at 0.15 within the model. This is slightly higher than the available estimates of Z and lower assumed values for M may have led, as they did in SARC-56 in 2013, to different results (although one sensitivity model that estimated M during fitting resulted in a similar level); a sensitivity model could have been run alongside the many others.*

   Sensitivity runs on $m$ were not attempted this time, but could be next time.

*11. The panel agreed that future stock assessments should include the following (see also Research Recommendations):*

1. *To address the reliability of the catch data, a verification program for reported catch and/or landings could be implemented. Observer coverage could also help better determine discarding patterns;*

   Observers now cover the Atlantic surfclam fleet.

2. *VMS information (which is available from vessels in this fishery) may be useful for verifying fishing locations and the distribution of fishing effort;*

   VMS data were included in this report (Appendix 1).

3. *Missing information from some strata in some surveys should be filled using more formal statistical imputation techniques rather than by borrowing data from other surveys;*

   This is no longer a critical issue after restratification.

4. *If assessment models are implemented at a much finer spatial scale than the current one, then the LPUE data may be much more useful and informative than they are in the current model; and*

5. *The panel recommends exploring different methods (including survey based methods, e.g. Needle (2015), and newer versions of catch curve analysis, e.g., Millar 2014) to derive estimates of M from the areas that have been unfished for extended periods of time.*

   These are both reasonable suggestions, but were not addressed this assessment cycle.

*In addition to the research recommendations in the assessment report, the panel discussed additional avenues of research that could improve the assessment of Atlantic surfclam (not prioritized).*

*1. The first main recommendation, from the Panel is to carefully consider any new changes made to the NEFSC clam survey. This survey provides the primary estimate of scale of the population,* *and its continuation will be important for stabilizing assessment estimates of biomass and fishing mortality rates. Changes in the survey could introduce problems in future assessments because changes in efficiency of the dredge (particularly to a less efficient one) would increase uncertainty in the population scale. Therefore, the panel recommends maintaining the current gear and vessel in any modification of the survey. If the spatial scope of the survey is expanded to include new regions, like Nantucket Shoals, it will be necessary to carefully consider how to treat the area of the stock for the previous survey. If there is a mismatch in scale, it could cause problems in interpreting changes in indices from one survey to another that surveyed a different spatial scale. Also, the survey has not been implemented as planned in the most recent years, with some areas not being fully surveyed in the intended year. This has caused problems for developing an index of abundance because of the need to aggregate data over years. If the survey for a region cannot be completed in the intended year, one way to improve estimates of the index would be to ensure that some of the strata are sampled in both years so that a "year effect" can be estimated for the survey index using a model-based approach.*

See Appendix 2.

*2. The assessment model assumed that an additional 12% of the landings were killed during fishing activities. The panel thought it likely that this value was size-dependent and may have changed with the prosecution of the fishery. This value should be reexamined using observed data, and re-estimated if necessary. Additionally, the value of incidental mortality may be able to be evaluated during a study that also estimates improved size-meat weight conversions.*

Not addressed, but see comment 4 above.

*3. The efficiency of the dredge is very important for setting the scale of the assessment model and interpreting results from the survey and comparing them to fishery removals. The panel recommends continuing to conduct the depletion experiments to estimate dredge efficiency and also to try to improve the experiments by better estimating the location of the dredge on the bottom. Video or acoustic instruments may be useful in more accurately determining the position of the dredge during depletion experiments.*

Depletion experiments are very expensive (require about 24 hours of ship time). The improvements to the survey and addtional data seem to have stabilized the estimation of scale in the assessment. Given the expense and return on value additional depletion experiments are unlikely to improve the assessment meaningfully.

*4. The panel recommends reexamining whether the structural decisions in the assessment model are leading to the conflicts among the data sources. Some of the most important structural decisions are assuming known selectivity for the survey (and its dome-shape), informative priors for survey gear efficiency, and the variation in size-at-age.*

Selectivity and growth are now mostly estimated.

*5. Methods to simultaneously estimate M within the assessment using data on shells from recently dead individuals could be considered if data are collected on recently deceased individuals (e.g., Wilberg et al. 2011).*

See comment 4 above.

*6. The panel recommends continuing to develop the institutional capacity and support for the use of age- and length-based integrated models.*

Agree.

*7. The panel recommends investigating spatial scales of variability in survey and commercial catch data as it may be useful in improving the design of the survey or in developing regions for assessment or management.*

A good idea that was not pursued in this assessment cycle.

*8. "Gap filling," where some data was duplicated or shared among years or strata, was used in the assessment to allow design-based estimators to be used to calculate survey CPUE. Model-based estimators have the potential to provide a more theoretically-based imputation method and should be further explored for the next assessment.*

Gap filling is less necessary due to the restratification. Model based estimators are still worth investigating but were not pursued this assessment cycle.

*9. The panel recommends that discard data from the new observer programme be considered for incorporation in the next assessment, if significant evidence of non-zero discarding exists.*

Discard data was explicitly included in this assessment.

*10. The panel suggests that the next assessment considers whether a combined state-federal assessment would be more appropriate, if it is possible to do so.*

State surveys are not regularly run anymore. The federal survey surveys in state waters. The only potential benefit to the assessment would be a survey of Nantucket Shoals, an area that is fished but not surveyed (it is too shallow). The state of Massachusetts does not currently survey the extent of the area concerned.

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## 2 Tables

Table 3: Surfclam discard estimates from 1982 through 1993. A minimum size regulation was in effect from 1982 through 1990. Within two years of dropping the minimum size regulation (1993) the discard rate within the surfclam fishery had dropped to zero and has remained zero since then.

| | Discards | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | NJ | DMV | Total | Landings (mt) | Discard proportion | Catch | Size limit (mm) |
| 1982 | 3,899 | 2,295 | 6,194 | 16,688 | 37.1% | 22,882 | 140 |
| 1983 | 2,507 | 2,127 | 4,634 | 18,592 | 24.9% | 23,226 | 140 |
| 1984 | 2,724 | 2,015 | 4,739 | 22,889 | 20.7% | 27,628 | 133 |
| 1985 | 2,186 | 1,725 | 3,911 | 22,480 | 17.4% | 26,391 | 127 |
| 1986 | 2,561 | 239 | 2,800 | 24,521 | 11.4% | 27,321 | 127 |
| 1987 | 1,475 | 415 | 1,890 | 21,744 | 8.7% | 23,634 | 127 |
| 1988 | 1,330 | 106 | 1,436 | 23,378 | 6.1% | 24,814 | 127 |
| 1989 | 1,054 | 258 | 1,312 | 21,888 | 6.0% | 23,200 | 127 |
| 1990 | 1,146 | 123 | 1,269 | 24,018 | 5.3% | 25,287 | 127 |
| 1991 | 561 | 5 | 566 | 20,615 | 2.7% | 21,181 | |
| 1992 | 1,020 | 4 | 1,024 | 21,686 | 4.7% | 22,710 | |
| 1993 | 0 | 0 | 0 | 21,859 | 0.0% | 21,859 | |

Table 4: Atlantic surfclam landings and EEZ quotas. All figures are meat weights in mt. Total landings for 1965-1981 are from NEFSC (2003) and other years were from a dealer database (CFDBS). EEZ landings for 1965-1982 are from NEFSC (2003) while later years are from a logbook database (SFOQVR). Landings for state waters are approximated as total landings - EEZ landings and may not accurately reflect state landings. Summary statistics ignore years without fishing.

| Year | Total | EEZ | State | $\frac{EEZ}{Total}$ | Quota |
|---|---|---|---|---|---|
| 1965 | 19998 | 14968 | 5030 | 0.75 | |
| 1966 | 20463 | 14696 | 5767 | 0.72 | |
| 1967 | 18168 | 11204 | 6964 | 0.62 | |
| 1968 | 18394 | 9072 | 9322 | 0.49 | |
| 1969 | 22487 | 7212 | 15275 | 0.32 | |
| 1970 | 30535 | 6396 | 24139 | 0.21 | |
| 1971 | 23829 | 22704 | 1125 | 0.95 | |
| 1972 | 28744 | 25071 | 3673 | 0.87 | |
| 1973 | 37362 | 32921 | 4441 | 0.88 | |
| 1974 | 43595 | 33761 | 9834 | 0.77 | |
| 1975 | 39442 | 20080 | 19362 | 0.51 | |
| 1976 | 22277 | 19304 | 2973 | 0.87 | |
| 1977 | 23149 | 19490 | 3659 | 0.84 | |
| 1978 | 17798 | 14240 | 3558 | 0.8 | 13880 |
| 1979 | 15836 | 13186 | 2650 | 0.83 | 13880 |
| 1980 | 17117 | 15748 | 1369 | 0.92 | 13882 |
| 1981 | 20910 | 16947 | 3963 | 0.81 | 13882 |
| 1982 | 23631 | 16688 | 6943 | 0.71 | 18506 |
| 1983 | 23631 | 18592 | 5039 | 0.79 | 18892 |
| 1984 | 30530 | 22889 | 7641 | 0.75 | 18892 |
| 1985 | 28316 | 22480 | 5836 | 0.79 | 21205 |
| 1986 | 35073 | 24521 | 10552 | 0.7 | 24290 |
| 1987 | 27231 | 21744 | 5487 | 0.8 | 24290 |
| 1988 | 28506 | 23378 | 5128 | 0.82 | 24290 |
| 1989 | 30081 | 21888 | 8193 | 0.73 | 25184 |
| 1990 | 32628 | 24018 | 8610 | 0.74 | 24282 |
| 1991 | 30794 | 20615 | 10179 | 0.67 | 21976 |
| 1992 | 33164 | 21686 | 11478 | 0.65 | 21976 |
| 1993 | 32878 | 21859 | 11019 | 0.66 | 21976 |
| 1994 | 32379 | 21943 | 10436 | 0.68 | 21976 |
| 1995 | 30061 | 19627 | 10434 | 0.65 | 19779 |
| 1996 | 28834 | 19827 | 9007 | 0.69 | 19779 |
| 1997 | 26311 | 18612 | 7699 | 0.71 | 19779 |
| 1998 | 24506 | 18234 | 6272 | 0.74 | 19779 |
| 1999 | 26677 | 19577 | 7100 | 0.73 | 19779 |
| 2000 | 31093 | 19778 | 11315 | 0.64 | 19779 |
| 2001 | 31237 | 22017 | 9220 | 0.7 | 21976 |
| 2002 | 32645 | 24006 | 8639 | 0.74 | 24174 |

*Continued*

Table 4: Table 4 Continued

| Year | Total | EEZ | State | $\frac{EEZ}{Total}$ | Quota |
|---|---|---|---|---|---|
| 2003 | 31526 | 24994 | 6532 | 0.79 | 25061 |
| 2004 | 26463 | 24197 | 2266 | 0.91 | 26218 |
| 2005 | 22734 | 21163 | 1571 | 0.93 | 26218 |
| 2006 | 25779 | 23573 | 2206 | 0.91 | 26218 |
| 2007 | 27091 | 24915 | 2176 | 0.92 | 26218 |
| 2008 | 25223 | 22510 | 2713 | 0.89 | 26218 |
| 2009 | 22396 | 20065 | 2331 | 0.9 | 26218 |
| 2010 | 19941 | 17984 | 1957 | 0.9 | 26218 |
| 2011 | 20044 | 18839 | 1205 | 0.94 | 26218 |
| 2012 | 18393 | 18054 | 339 | 0.98 | 26218 |
| 2013 | 18924 | 18551 | 373 | 0.98 | 26218 |
| 2014 | 18834 | 18227 | 607 | 0.97 | 26218 |
| 2015 | 18517 | 19119 | 0 | 1.03 | 26218 |
| 2016 | 18202 | 18339 | 0 | 1.01 | 26218 |
| 2017 | 17690 | 16902 | 788 | 0.96 | 26218 |
| 2018 | 17114 | 16269 | 845 | 0.95 | 26218 |
| 2019 | 16502 | 14983 | 1519 | 0.91 | 26218 |
| min | 15836 | 6396 | 0 | 0.21 | 13880 |
| max | 43595 | 33761 | 24139 | 1.03 | 26218 |
| mean | 25558 | 19630 | 5941 | 0.78 | 22682 |

Table 5: EEZ surfclam landings (mt meats) by stock assessment area and year. Summary statistics ignore years without fishing.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 1979 | | 12087 | 1099 | | | | | 13186 |
| 1980 | 64 | 12789 | 2878 | 17 | | | | 15748 |
| 1981 | 568 | 7472 | 8820 | 87 | | | | 16947 |
| 1982 | 1705 | 6679 | 8086 | 94 | 124 | | | 16688 |
| 1983 | 2226 | 7173 | 8095 | 263 | 835 | | | 18592 |
| 1984 | 1797 | 5978 | 11905 | 7 | 382 | 2765 | 54 | 22889 |
| 1985 | 741 | 7856 | 11245 | | 452 | 2185 | | 22480 |
| 1986 | 529 | 2853 | 17731 | 18 | 1223 | 1991 | 176 | 24521 |
| 1987 | 378 | 1303 | 18017 | | 1140 | 907 | | 21744 |
| 1988 | 558 | 1149 | 19420 | | 1512 | 739 | | 23378 |
| 1989 | 439 | 3123 | 16532 | | 1361 | 434 | | 21888 |
| 1990 | 1502 | 3546 | 17886 | | 998 | 7 | 79 | 24018 |
| 1991 | | 1634 | 18912 | 15 | 33 | | 21 | 20615 |
| 1992 | | 1221 | 20399 | 61 | 5 | | | 21686 |
| 1993 | | 3416 | 18378 | 62 | 3 | | | 21859 |
| 1994 | | 3454 | 18418 | 71 | | | | 21943 |
| 1995 | | 2752 | 16497 | | 378 | | | 19627 |
| 1996 | | 2239 | 17480 | 26 | 82 | | | 19827 |
| 1997 | | 1540 | 16999 | 73 | | | | 18612 |
| 1998 | | 484 | 17511 | 117 | 121 | | | 18234 |
| 1999 | | 649 | 18755 | 157 | 16 | | | 19577 |
| 2000 | | 2041 | 17513 | 121 | 103 | | | 19778 |
| 2001 | | 3282 | 17719 | 935 | 81 | | | 22017 |
| 2002 | 64 | 4489 | 18271 | 1130 | 52 | | | 24006 |
| 2003 | | 1432 | 21669 | 1626 | 267 | | | 24994 |
| 2004 | | 1482 | 19197 | 906 | 2612 | | | 24197 |
| 2005 | | 1668 | 16851 | 759 | 1885 | | | 21163 |
| 2006 | | 2773 | 19660 | 245 | 895 | | | 23573 |
| 2007 | | 3073 | 20267 | 1117 | 458 | | | 24915 |
| 2008 | | 3261 | 17517 | 1309 | 423 | | | 22510 |
| 2009 | | 1977 | 14834 | 1798 | 1444 | 11 | | 20065 |
| 2010 | | 1556 | 11065 | 1181 | 2870 | 1311 | | 17984 |
| 2011 | | 1445 | 12055 | 400 | 2552 | 2387 | | 18839 |
| 2012 | | 3784 | 6175 | 307 | 4142 | 3646 | | 18054 |
| 2013 | | 3599 | 5359 | 231 | 4959 | 4403 | | 18551 |
| 2014 | | 3544 | 6063 | 306 | 5079 | 3236 | | 18227 |
| 2015 | | 2906 | 6408 | 941 | 4759 | 4104 | | 19119 |
| 2016 | | 2100 | 6046 | 1239 | 4117 | 4837 | | 18339 |
| 2017 | | 1951 | 6873 | 519 | 2740 | 4819 | | 16902 |
| 2018 | | 2282 | 6633 | 525 | 2867 | 3962 | | 16269 |
| 2019 | | 2730 | 6193 | 363 | 2448 | 3247 | 2 | 14983 |
| min | 64 | 484 | 1099 | 7 | 3 | 7 | 2 | 13186 |

*Continued*

Table 5: Table 5 Continued

| Year | SVA | DMV | NJ | LI | SNE | GBK | Other | Total |
|---|---|---|---|---|---|---|---|---|
| max | 2226 | 12789 | 21669 | 1798 | 5079 | 4837 | 176 | 24994 |
| mean | 224 | 2893 | 13372 | 412 | 1291 | 1076 | 8 | 20208 |

Table 6: EEZ fishing effort (hours fished by all vessels) for surfclam, by stock assessment area and year based on logbook data. Summary statistics ignore years without fishing.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 1981 | 1337 | 15839 | 16770 | 204 | | | | 34150 |
| 1982 | 2790 | 18050 | 24635 | 225 | 136 | | | 45837 |
| 1983 | 4190 | 18805 | 23584 | 536 | 1130 | | | 48244 |
| 1984 | 2603 | 8972 | 20819 | 27 | 1264 | 1732 | 42 | 35459 |
| 1985 | 397 | 4687 | 10518 | | 1702 | 2608 | | 19912 |
| 1986 | 236 | 1630 | 10764 | 38 | 2516 | 1610 | 675 | 17469 |
| 1987 | 262 | 722 | 11910 | | 3781 | 1006 | | 17681 |
| 1988 | 322 | 593 | 13175 | | 5274 | 587 | | 19950 |
| 1989 | 228 | 1616 | 11794 | | 4741 | 389 | | 18768 |
| 1990 | 1150 | 2065 | 12437 | | 3032 | | 898 | 19582 |
| 1991 | | 1254 | 17243 | 20 | 107 | | 292 | 18916 |
| 1992 | | 797 | 21379 | 67 | | | | 22243 |
| 1993 | | 2423 | 18232 | 56 | 15 | | | 20726 |
| 1994 | | 1930 | 21495 | 70 | | | | 23495 |
| 1995 | | 1560 | 18625 | | 1058 | | | 21243 |
| 1996 | | 1577 | 20994 | 40 | 287 | | | 22899 |
| 1997 | | 1098 | 20383 | 77 | | | | 21558 |
| 1998 | | 289 | 19608 | 134 | 519 | | | 20550 |
| 1999 | | 734 | 18146 | 150 | 148 | | | 19179 |
| 2000 | | 1859 | 16787 | 114 | 368 | | | 19128 |
| 2001 | | 2537 | 18461 | 962 | 148 | | | 22107 |
| 2002 | 112 | 5505 | 19826 | 1240 | 62 | | | 26746 |
| 2003 | | 2347 | 25091 | 1827 | 177 | | | 29442 |
| 2004 | | 3161 | 26414 | 1252 | 1092 | | | 31919 |
| 2005 | | 2660 | 24391 | 1208 | 1322 | | | 29581 |
| 2006 | | 5883 | 27157 | 343 | 1033 | | | 34416 |
| 2007 | | 7065 | 34703 | 1585 | 960 | | | 44313 |
| 2008 | | 8154 | 33947 | 2294 | 541 | | | 44936 |
| 2009 | | 5667 | 33519 | 4085 | 2520 | 12 | | 45803 |
| 2010 | | 4125 | 31779 | 3297 | 5590 | 495 | | 45287 |
| 2011 | | 3074 | 35329 | 1309 | 7748 | 974 | | 48434 |
| 2012 | | 7402 | 21665 | 931 | 11479 | 2040 | | 43517 |
| 2013 | | 6132 | 19931 | 858 | 15921 | 3811 | | 46653 |
| 2014 | | 6660 | 18186 | 1031 | 17078 | 2946 | | 45901 |
| 2015 | | 6708 | 19510 | 3420 | 17060 | 4600 | | 51297 |
| 2016 | | 6630 | 23715 | 4511 | 17962 | 5723 | | 58541 |
| 2017 | | 5965 | 31017 | 2825 | 12433 | 6419 | | 58659 |
| 2018 | | 6681 | 25741 | 2735 | 10416 | 5783 | | 51356 |
| 2019 | | 8436 | 23811 | 2016 | 13007 | 5646 | 14 | 52930 |
| min | 112 | 289 | 10518 | 20 | 15 | 12 | 14 | 17469 |
| max | 4190 | 18805 | 35329 | 4511 | 17962 | 6419 | 898 | 58659 |
| mean | 311 | 5455 | 20483 | 960 | 3944 | 1114 | 46 | 33303 |

Table 7: Real and nominal exvessel prices and revenues for surfclam based on dealer data. Average price was computed as total revenues divided by total landed meat weight during each year, rather than as annual averages of prices for individual trips, to reduce effects of small deliveries at relatively high prices. The consumer price index (CPI) used to convert nominal dollars to 2009 equivalent dollars is for unprocessed and packaged fish, which includes shellfish and finfish (Eric Thunberg, NEFSC, pers. comm.).

| Year | CPI | Nominal.Prices | Real.Prices | Nominal.Revenue | Real.Revenue |
|---|---|---|---|---|---|
| 1982 | 0.45 | 8.94 | 19.87 | 25.19 | 55.98 |
| 1983 | 0.46 | 7.57 | 16.31 | 23.21 | 49.98 |
| 1984 | 0.48 | 8.37 | 17.29 | 33.16 | 68.45 |
| 1985 | 0.50 | 9.34 | 18.62 | 34.30 | 68.38 |
| 1986 | 0.51 | 9.20 | 18.00 | 41.84 | 81.89 |
| 1987 | 0.53 | 7.83 | 14.78 | 27.64 | 52.20 |
| 1988 | 0.55 | 7.80 | 14.14 | 28.83 | 52.27 |
| 1989 | 0.58 | 7.78 | 13.45 | 30.33 | 52.47 |
| 1990 | 0.61 | 7.66 | 12.56 | 32.39 | 53.16 |
| 1991 | 0.63 | 7.51 | 11.82 | 29.98 | 47.21 |
| 1992 | 0.65 | 7.40 | 11.32 | 31.83 | 48.67 |
| 1993 | 0.67 | 7.83 | 11.62 | 33.37 | 49.53 |
| 1994 | 0.69 | 9.82 | 14.22 | 41.24 | 59.69 |
| 1995 | 0.71 | 10.58 | 14.89 | 41.25 | 58.05 |
| 1996 | 0.73 | 10.24 | 13.99 | 38.27 | 52.33 |
| 1997 | 0.75 | 10.31 | 13.78 | 35.19 | 47.03 |
| 1998 | 0.76 | 9.19 | 12.09 | 29.20 | 38.43 |
| 1999 | 0.78 | 8.79 | 11.32 | 30.42 | 39.17 |
| 2000 | 0.80 | 9.43 | 11.75 | 38.02 | 47.37 |
| 2001 | 0.83 | 9.76 | 11.83 | 39.55 | 47.91 |
| 2002 | 0.84 | 9.45 | 11.26 | 39.99 | 47.68 |
| 2003 | 0.86 | 9.64 | 11.24 | 39.43 | 45.96 |
| 2004 | 0.88 | 9.40 | 10.67 | 32.24 | 36.61 |
| 2005 | 0.91 | 9.41 | 10.33 | 27.73 | 30.45 |
| 2006 | 0.94 | 10.08 | 10.72 | 33.69 | 35.85 |
| 2007 | 0.97 | 10.48 | 10.85 | 36.84 | 38.12 |
| 2008 | 1.00 | 10.96 | 10.92 | 35.86 | 35.72 |
| 2009 | 1.00 | 11.46 | 11.46 | 33.30 | 33.30 |
| 2010 | 1.02 | 11.70 | 11.50 | 30.25 | 29.75 |
| 2011 | 1.05 | 11.61 | 11.07 | 30.17 | 28.78 |
| 2012 | 1.07 | 12.34 | 11.53 | 29.44 | 27.51 |
| 2013 | 1.09 | 12.11 | 11.14 | 29.71 | 27.35 |
| 2014 | 1.10 | 12.24 | 11.09 | 29.90 | 27.09 |
| 2015 | 1.10 | 12.64 | 11.46 | 30.35 | 27.51 |
| 2016 | 1.10 | 12.89 | 11.69 | 30.43 | 27.58 |
| 2017 | 1.10 | 13.88 | 12.58 | 31.83 | 28.86 |
| 2018 | 1.10 | 14.01 | 12.70 | 31.09 | 28.18 |
| 2019 | 1.10 | 14.27 | 12.93 | 30.53 | 27.68 |

*Continued*

Table 7: Table 7 Continued

| Year | CPI | Nominal.Prices | Real.Prices | Nominal.Revenue | Real.Revenue |
|---|---|---|---|---|---|

Table 8: Nominal landings per unit effort (LPUE, bushels $h^{-1}$) for surfclam fishing (all vessels) in the US EEZ from logbooks. LPUE is total landings in bushels divided by total hours fished. Summary statistics ignore years without fishing.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 1981 | 55.1 | 61.2 | 68.2 | 55.3 | | | | 64.4 |
| 1982 | 79.3 | 48 | 42.6 | 54.2 | 118.2 | | | 47.2 |
| 1983 | 68.9 | 49.5 | 44.5 | 63.6 | 95.8 | | | 50 |
| 1984 | 89.5 | 86.4 | 74.2 | 33.6 | 39.2 | 207 | 166.7 | 83.7 |
| 1985 | 242.1 | 217.4 | 138.6 | | 34.4 | 108.7 | | 146.4 |
| 1986 | 290.7 | 227 | 213.6 | 61.4 | 63 | 160.4 | 33.8 | 182 |
| 1987 | 187.1 | 234 | 196.2 | | 39.1 | 116.9 | | 159.5 |
| 1988 | 224.7 | 251.3 | 191.2 | | 37.2 | 163.3 | | 152 |
| 1989 | 249.7 | 250.6 | 181.8 | | 37.2 | 144.7 | | 151.2 |
| 1990 | 169.4 | 222.7 | 186.5 | | 42.7 | | 11.4 | 159.1 |
| 1991 | | 169 | 142.2 | 97.3 | 40 | | 9.3 | 141.3 |
| 1992 | | 198.7 | 123.7 | 118.1 | | | | 126.4 |
| 1993 | | 182.8 | 130.7 | 143.6 | 25.9 | | | 136.8 |
| 1994 | | 232.1 | 111.1 | 131.5 | | | | 121.1 |
| 1995 | | 228.8 | 114.9 | | 46.3 | | | 119.8 |
| 1996 | | 184.1 | 108 | 84.3 | 37.1 | | | 112.3 |
| 1997 | | 181.9 | 108.2 | 122.9 | | | | 112 |
| 1998 | | 217.2 | 115.8 | 113.2 | 30.2 | | | 115.1 |
| 1999 | | 114.7 | 134 | 135.7 | 14 | | | 132.4 |
| 2000 | | 142.4 | 135.3 | 137.6 | 36.3 | | | 134.1 |
| 2001 | | 167.8 | 124.5 | 126 | 71 | | | 129.2 |
| 2002 | 74.1 | 105.8 | 119.5 | 118.2 | 108.8 | | | 116.4 |
| 2003 | | 79.1 | 112 | 115.4 | 195.6 | | | 110.1 |
| 2004 | | 60.8 | 94.3 | 93.8 | 310.2 | | | 98.3 |
| 2005 | | 81.3 | 89.6 | 81.5 | 184.9 | | | 92.8 |
| 2006 | | 61.1 | 93.9 | 92.6 | 112.4 | | | 88.8 |
| 2007 | | 56.4 | 75.7 | 91.4 | 61.9 | | | 72.9 |
| 2008 | | 51.9 | 66.9 | 74 | 101.4 | | | 65 |
| 2009 | | 45.2 | 57.4 | 57.1 | 74.3 | 118.9 | | 56.8 |
| 2010 | | 48.9 | 45.2 | 46.5 | 66.6 | 343.5 | | 51.5 |
| 2011 | | 61 | 44.3 | 39.6 | 42.7 | 317.8 | | 50.4 |
| 2012 | | 66.3 | 37 | 42.8 | 46.8 | 231.8 | | 53.8 |
| 2013 | | 76.1 | 34.9 | 34.9 | 40.4 | 149.8 | | 51.6 |
| 2014 | | 69 | 43.2 | 38.5 | 38.6 | 142.5 | | 51.5 |
| 2015 | | 56.2 | 42.6 | 35.7 | 36.2 | 115.7 | | 48.3 |
| 2016 | | 41.1 | 33.1 | 35.6 | 29.7 | 109.6 | | 40.6 |
| 2017 | | 42.7 | 28.7 | 23.8 | 28.6 | 97.4 | | 37.4 |
| 2018 | | 44.3 | 33.4 | 24.9 | 35.7 | 88.8 | | 41.1 |
| 2019 | | 42 | 33.7 | 23.4 | 24.4 | 74.5 | 18.5 | 36.7 |
| min | 55.1 | 41.1 | 28.7 | 23.4 | 14 | 74.5 | 9.3 | 36.7 |
| max | 290.7 | 251.3 | 213.6 | 143.6 | 310.2 | 343.5 | 166.7 | 182 |

*Continued*

Table 8: Table 8 Continued

| Year | SVA | DMV | NJ | LI | SNE | GBK | Other | Total |
|---|---|---|---|---|---|---|---|---|
| mean | 311 | 5455 | 20483 | 960 | 3944 | 1114 | 46 | 95.9 |

Table 9: Numbers of commercial trips sampled and numbers of surfclams measured in port samples from landings during 1982-2019, by region. Numbers of trips during 1982-1999 were estimated assuming 30 individuals sampled per trip, as specified in port sample instructions.

| | SVA | | DMV | | NJ | | LI | | SNE | | GBK | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Lengths | Trips | Lengths | Trips | Lengths | Trips | Lengths | Trips | Lengths | Trips | Lengths | Trips |
| 1982 | 30 | 1 | 7756 | 259 | 7477 | 249 | | | 30 | 1 | | |
| 1983 | 30 | 1 | 5923 | 197 | 11253 | 375 | | | 30 | 1 | | |
| 1984 | 90 | 3 | 3066 | 102 | 12751 | 425 | | | 90 | 3 | 30 | 1 |
| 1985 | | | 1832 | 61 | 7674 | 256 | | | 150 | 5 | 275 | 15 |
| 1986 | 23 | 1 | 1260 | 42 | 5130 | 171 | | | 330 | 11 | 143 | 7 |
| 1987 | | | 730 | 24 | 900 | 30 | | | 569 | 19 | | |
| 1988 | | | 420 | 14 | 900 | 30 | | | 810 | 27 | | |
| 1989 | | | 866 | 29 | 919 | 31 | | | 449 | 15 | | |
| 1990 | | | 892 | 30 | 901 | 30 | | | 209 | 7 | | |
| 1991 | | | 1080 | 36 | 2272 | 76 | | | | | | |
| 1992 | | | 1170 | 39 | 1710 | 57 | | | | | | |
| 1993 | | | 1392 | 46 | 928 | 31 | 1127 | 56 | | | | |
| 1994 | | | 119 | 4 | 900 | 30 | | | | | | |
| 1995 | | | 720 | 24 | 510 | 17 | | | | | | |
| 1996 | | | 1154 | 38 | 1117 | 37 | | | | | | |
| 1997 | | | 1622 | 54 | 957 | 32 | | | | | | |
| 1998 | | | 1560 | 52 | 690 | 23 | | | | | | |
| 1999 | | | 1720 | 57 | 856 | 29 | | | | | | |
| 2000 | | | 600 | 20 | 3315 | 111 | 102 | 8 | | | | |
| 2001 | | | 970 | 33 | 1260 | 42 | | | | | | |
| 2002 | | | 210 | 7 | 1111 | 37 | | | | | | |
| 2003 | | | 60 | 2 | 2455 | 80 | | | | | | |
| 2004 | | | 18 | 1 | 425 | 21 | 30 | 1 | | | | |
| 2005 | | | 410 | 18 | 1250 | 62 | 150 | 5 | | | | |
| 2006 | | | 1074 | 50 | 940 | 47 | 83 | 4 | | | | |
| 2007 | | | 1582 | 67 | 1568 | 80 | 198 | 11 | | | | |
| 2008 | | | 1195 | 55 | 1317 | 67 | 441 | 24 | | | | |
| 2009 | | | 697 | 31 | 1148 | 57 | 349 | 18 | | | | |
| 2010 | | | 450 | 20 | 1064 | 49 | 374 | 20 | 1590 | 80 | 30 | 1 |
| 2011 | | | 578 | 26 | 2558 | 119 | 994 | 47 | 1630 | 81 | 275 | 15 |
| 2012 | 30 | 1 | 919 | 40 | 1213 | 58 | 774 | 38 | 941 | 43 | 143 | 7 |
| 2013 | | | 604 | 27 | 1621 | 75 | 1127 | 56 | 145 | 7 | 220 | 11 |
| 2014 | | | 325 | 16 | 1118 | 51 | 614 | 30 | 481 | 23 | 482 | 25 |
| 2015 | | | 521 | 24 | 843 | 40 | 210 | 10 | 47 | 2 | 202 | 10 |
| 2016 | | | 336 | 15 | 888 | 42 | 170 | 8 | 30 | 1 | 328 | 17 |
| 2017 | | | 253 | 12 | 828 | 38 | 132 | 7 | | | 1139 | 61 |
| 2018 | | | 160 | 10 | 664 | 44 | 175 | 9 | 90 | 3 | 1845 | 93 |
| 2019 | | | 356 | 17 | 1438 | 67 | 143 | 7 | | | 1022 | 65 |
| min | 23 | 1 | 18 | 1 | 425 | 17 | 30 | 1 | 30 | 1 | 30 | 1 |
| max | 90 | 3 | 7756 | 259 | 12751 | 425 | 1127 | 56 | 1630 | 81 | 1845 | 93 |
| mean | 41 | 1 | 1174 | 42 | 2233 | 82 | 400 | 20 | 448 | 19 | 472 | 25 |

Table 10: Number of successful random tows in NEFSC clam surveys used for survey trends and efficiency corrected swept area biomass. 'Holes' (unsampled survey strata in some years) were filled by borrowing from adjacent surveys were possible (borrowed totals are negative numbers in gray shaded boxes). Holes that could not be filled have zeros in black boxes. Survey strata are grouped by region. In 2012 and later the NEFSC survey was conducted from a commercial platform using different gear, and tows were not borrowed across gear types. Starting in 2012, not all regions were sampled in each survey year. Instead the survey was conducted in either the northern or southern area. Areas intentionally not sampled are left blank in those years. 2014 was not intended to be a survey year, but some strata were sampled in order to fill holes left over from 2013. 6S was surveyed in 2013, but the survey results were borowed to 2012 and not used in 2013. The NEFSC clam survey was restratified in 2018 and strata that were surveyed off cycle (e.g. 3S in 2014) were surveyed under the previous stratification.

| Strata | 1982 | 1983 | 1984 | 1986 | 1989 | 1992 | 1994 | 1997 | 1999 | 2002 | 2005 | 2008 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | **SVAtoSNE** | | | | | | | | | | |
| 1S | 34 | 39 | 55 | 40 | 50 | 50 | 51 | 52 | 38 | 52 | 44 | 31 | 24 | 17 | | | 15 | | 9 | |
| 2S | 20 | 17 | 20 | 21 | 21 | 20 | 21 | 21 | 19 | 28 | 18 | 21 | 20 | 29 | | | 12 | | 9 | |
| 3S | 65 | 66 | 76 | 69 | 71 | 71 | 75 | 84 | 88 | 80 | 69 | 84 | 45 | 28 | | | 43 | | 118 | |
| 4S | 10 | 10 | 5 | 12 | 12 | 12 | 16 | 12 | 12 | 12 | 12 | 8 | 37 | 17 | | | 18 | | 11 | |
| 5S | 36 | 37 | 57 | 41 | 46 | 45 | 44 | 48 | 49 | 47 | 40 | 52 | 42 | 30 | | | 53 | | 23 | |
| 6S | 9 | 38 | 25 | 12 | 11 | 14 | 15 | 15 | 11 | 9 | 6 | 12 | 18 | -14 | 14 | 2 | 5 | 8 | 8 | |
| | | | | | | | | | | **GBK** | | | | | | | | | | |
| 7S | 1 | -4 | 3 | 3 | -6 | 3 | 3 | 3 | -3 | 0 | -2 | 2 | 2 | | -5 | 5 | | 8 | | 10 |
| 8S | 3 | 7 | 5 | 15 | 13 | 17 | 18 | 17 | 10 | 2 | -12 | 10 | 21 | | 12 | 9 | | 34 | | 57 |
| 9S | 1 | 3 | -7 | 4 | 5 | 8 | 11 | 8 | 7 | 7 | -14 | 7 | 28 | | 33 | | | 25 | | 23 |
| 10S | 2 | -2 | -2 | 2 | -4 | 2 | 4 | 3 | -4 | 1 | -1 | -3 | 3 | | 4 | | | 8 | | 9 |
| 11S | 4 | 1 | 15 | 6 | 20 | 19 | 19 | 19 | 11 | 5 | -18 | 13 | 9 | | 10 | 5 | | 31 | | 60 |
| 12S | 3 | -5 | 2 | 7 | 1 | 6 | 7 | 7 | 4 | 6 | -10 | 4 | 15 | | 9 | | | 19 | | 22 |

Table 11: Trends in abundance and biomass for surfclam > 50 mm shell length during 1982-2019 based on NEFSC clam survey data. Survey values are the clams caught in the survey dredge. Stock values are the survey values adjusted to account for the selectivity of the survey dredge. Fishable values are the stock values adjusted to account for the selectivity of a commercial dredge. Figures include original plus borrowed tows. The column "N strata" includes strata sampled by tows borrowed from the previous and subsequent surveys if needed.

| | **Survey** | | | | **Stock** | | | | **Fishable** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | N tows | Pos. tows | N strata |
| | | | | | | | | **SVAtoSNE** | | | | | | | |
| 1982 | 0.206 | 0.336 | 0.019 | 0.280 | 0.249 | 0.342 | 0.021 | 0.293 | 0.206 | 0.336 | 0.019 | 0.280 | 174 | 117 | 6 |
| 1983 | 0.107 | 0.239 | 0.012 | 0.189 | 0.127 | 0.219 | 0.013 | 0.188 | 0.107 | 0.239 | 0.012 | 0.189 | 207 | 139 | 6 |
| 1984 | 0.114 | 0.191 | 0.012 | 0.139 | 0.181 | 0.252 | 0.013 | 0.147 | 0.114 | 0.191 | 0.012 | 0.139 | 238 | 174 | 6 |
| 1986 | 0.105 | 0.187 | 0.012 | 0.164 | 0.129 | 0.179 | 0.013 | 0.162 | 0.105 | 0.187 | 0.012 | 0.164 | 195 | 141 | 6 |
| 1989 | 0.078 | 0.115 | 0.010 | 0.109 | 0.098 | 0.123 | 0.010 | 0.109 | 0.078 | 0.115 | 0.010 | 0.109 | 211 | 150 | 6 |
| 1992 | 0.077 | 0.149 | 0.009 | 0.131 | 0.101 | 0.137 | 0.009 | 0.128 | 0.077 | 0.149 | 0.009 | 0.131 | 212 | 155 | 6 |
| 1994 | 0.266 | 0.158 | 0.026 | 0.155 | 0.605 | 0.349 | 0.031 | 0.161 | 0.266 | 0.158 | 0.026 | 0.155 | 222 | 175 | 6 |
| 1997 | 0.198 | 0.105 | 0.024 | 0.107 | 0.229 | 0.100 | 0.025 | 0.105 | 0.198 | 0.105 | 0.024 | 0.107 | 232 | 183 | 6 |
| 1999 | 0.115 | 0.194 | 0.015 | 0.184 | 0.136 | 0.176 | 0.016 | 0.181 | 0.115 | 0.194 | 0.015 | 0.184 | 217 | 155 | 6 |
| 2002 | 0.094 | 0.102 | 0.012 | 0.109 | 0.119 | 0.104 | 0.013 | 0.106 | 0.094 | 0.102 | 0.012 | 0.109 | 228 | 178 | 6 |
| 2005 | 0.048 | 0.132 | 0.006 | 0.127 | 0.060 | 0.127 | 0.006 | 0.124 | 0.048 | 0.132 | 0.006 | 0.127 | 189 | 130 | 6 |
| 2008 | 0.049 | 0.125 | 0.005 | 0.143 | 0.082 | 0.115 | 0.006 | 0.134 | 0.049 | 0.125 | 0.005 | 0.143 | 208 | 154 | 6 |
| 2011 | 0.074 | 0.157 | 0.007 | 0.146 | 0.120 | 0.153 | 0.008 | 0.141 | 0.074 | 0.157 | 0.007 | 0.146 | 186 | 122 | 6 |
| 2012 | 0.127 | 0.177 | 0.015 | 0.176 | 0.141 | 0.173 | 0.016 | 0.174 | 0.127 | 0.177 | 0.015 | 0.176 | 135 | 104 | 6 |
| 2013 | 0.014 | 0.437 | 0.003 | 0.414 | 0.014 | 0.437 | 0.003 | 0.414 | 0.014 | 0.437 | 0.003 | 0.414 | 14 | 6 | 1 |
| 2015 | 0.164 | 0.163 | 0.014 | 0.144 | 0.188 | 0.161 | 0.015 | 0.143 | 0.164 | 0.163 | 0.014 | 0.144 | 146 | 118 | 6 |
| 2016 | 0.088 | 0.921 | 0.014 | 0.935 | 0.093 | 0.919 | 0.015 | 0.934 | 0.088 | 0.921 | 0.014 | 0.935 | 8 | 4 | 1 |
| 2018 | 0.149 | 0.127 | 0.013 | 0.118 | 0.174 | 0.125 | 0.014 | 0.117 | 0.149 | 0.127 | 0.013 | 0.118 | 178 | 137 | 6 |
| | | | | | | | | **GBK** | | | | | | | |
| 1982 | 0.022 | 0.351 | 0.002 | 0.325 | 0.049 | 0.299 | 0.002 | 0.307 | 0.022 | 0.351 | 0.002 | 0.325 | 14 | 11 | 6 |
| 1983 | 0.018 | 0.519 | 0.002 | 0.562 | 0.029 | 0.478 | 0.002 | 0.536 | 0.018 | 0.519 | 0.002 | 0.562 | 22 | 13 | 6 |
| 1984 | 0.068 | 0.632 | 0.011 | 0.812 | 0.101 | 0.441 | 0.012 | 0.768 | 0.068 | 0.632 | 0.011 | 0.812 | 34 | 18 | 6 |
| 1986 | 0.103 | 0.747 | 0.006 | 0.569 | 0.361 | 0.848 | 0.011 | 0.666 | 0.103 | 0.747 | 0.006 | 0.569 | 37 | 17 | 6 |
| 1989 | 0.073 | 0.557 | 0.010 | 0.585 | 0.084 | 0.506 | 0.010 | 0.574 | 0.073 | 0.557 | 0.010 | 0.585 | 49 | 24 | 6 |
| 1992 | 0.123 | 0.536 | 0.010 | 0.471 | 0.198 | 0.476 | 0.012 | 0.466 | 0.123 | 0.536 | 0.010 | 0.471 | 55 | 39 | 6 |

*Continued*

Table 11: Table 11 Continued

| Year | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | $\frac{N}{m^2}$ | CV | $\frac{kg}{m^2}$ | CV | N tows | Pos. tows | N strata |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1994 | 0.241 | 0.305 | 0.027 | 0.343 | 0.310 | 0.270 | 0.029 | 0.332 | 0.241 | 0.305 | 0.027 | 0.343 | 62 | 45 | 6 |
| 1997 | 0.246 | 0.259 | 0.021 | 0.259 | 0.342 | 0.238 | 0.024 | 0.250 | 0.246 | 0.259 | 0.021 | 0.259 | 57 | 42 | 6 |
| 1999 | 0.173 | 0.473 | 0.017 | 0.459 | 0.225 | 0.451 | 0.019 | 0.459 | 0.173 | 0.473 | 0.017 | 0.459 | 39 | 26 | 6 |
| 2002 | 0.067 | 0.531 | 0.009 | 0.640 | 0.093 | 0.436 | 0.010 | 0.614 | 0.067 | 0.531 | 0.009 | 0.640 | 21 | 12 | 5 |
| 2005 | 0.097 | 0.268 | 0.013 | 0.285 | 0.118 | 0.231 | 0.013 | 0.278 | 0.097 | 0.268 | 0.013 | 0.285 | 57 | 37 | 6 |
| 2008 | 0.108 | 0.309 | 0.014 | 0.326 | 0.123 | 0.279 | 0.015 | 0.320 | 0.108 | 0.309 | 0.014 | 0.326 | 39 | 28 | 6 |
| 2011 | 0.118 | 0.251 | 0.015 | 0.272 | 0.133 | 0.233 | 0.016 | 0.268 | 0.118 | 0.251 | 0.015 | 0.272 | 78 | 47 | 6 |
| 2013 | 0.060 | 0.505 | 0.007 | 0.487 | 0.063 | 0.501 | 0.007 | 0.487 | 0.060 | 0.505 | 0.007 | 0.487 | 73 | 26 | 6 |
| 2016 | 0.062 | 0.293 | 0.008 | 0.289 | 0.065 | 0.291 | 0.009 | 0.289 | 0.062 | 0.293 | 0.008 | 0.289 | 125 | 78 | 6 |
| 2019 | 0.018 | 0.190 | 0.003 | 0.184 | 0.019 | 0.188 | 0.003 | 0.184 | 0.018 | 0.190 | 0.003 | 0.184 | 180 | 99 | 6 |

Table 12: Shell length composition data used to estimate dredge selectivity for surfclams between 2012 and 2016. Number of surfclams caught (no.) and positive stations (pos.) for the modified commercial dredge used for the NEFSC survey and a lined dredge presumed to catch all animals available. Some of the stations were targeting ocean quahog and few surfclams were captured at these sites.

| SL group | Lined no. | Survey no. | Lined pos. | Survey pos. |
|---|---|---|---|---|
| 0-10 | 0 | 0 | 0 | 0 |
| 10-20 | 1 | 0 | 1 | 0 |
| 20-30 | 5 | 0 | 2 | 0 |
| 30-40 | 18 | 0 | 7 | 0 |
| 40-50 | 33 | 0 | 8 | 0 |
| 50-60 | 55 | 0 | 8 | 0 |
| 60-70 | 46 | 0 | 7 | 0 |
| 70-80 | 46 | 9 | 6 | 3 |
| 80-90 | 65 | 42 | 8 | 3 |
| 90-100 | 91 | 145 | 6 | 6 |
| 100-110 | 135 | 213 | 6 | 5 |
| 110-120 | 110 | 198 | 5 | 6 |
| 120-130 | 75 | 222 | 5 | 5 |
| 130-140 | 89 | 277 | 4 | 4 |
| 140-150 | 91 | 308 | 4 | 4 |
| 150-160 | 75 | 289 | 3 | 3 |
| 160-170 | 40 | 164 | 3 | 2 |
| 170-180 | 5 | 18 | 2 | 2 |
| 180-190 | 0 | 4 | 0 | 1 |
| 190-200 | 1 | 0 | 1 | 0 |

Table 13: Numbers of surfclams in survey dredge selectivity experiments by length bin and station between 2012 and 2016. For example, 3:8 in the row corresponding to shell length (SL) bin 40−50 indicates that 3 surfclams between 40 and 50 mm were caught in the survey dredge and 8 surfclams were caught in the selectivity dredge at that station. Stations with very few total surfclams caught were ocean quahog stations, but are included for completeness.

| SL bin | Sta 33 | Sta 53 | Sta 59 | Sta 67 | Sta 77 | Sta 113 | Sta 117 | Sta 150 | Sta 182 |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 |
| 10-20 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 1:0 | 0:0 |
| 20-30 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 2:0 | 3:0 |
| 30-40 | 3:0 | 4:0 | 0:0 | 1:0 | 2:0 | 1:0 | 0:0 | 4:0 | 3:0 |
| 40-50 | 7:0 | 6:0 | 1:0 | 1:0 | 1:0 | 5:0 | 0:0 | 8:0 | 4:0 |
| 50-60 | 10:0 | 8:0 | 0:0 | 1:0 | 3:0 | 26:0 | 0:0 | 3:0 | 3:0 |
| 60-70 | 2:0 | 2:0 | 0:0 | 0:0 | 3:0 | 30:0 | 1:0 | 7:0 | 0:0 |
| 70-80 | 1:4 | 1:0 | 0:0 | 0:0 | 3:0 | 38:4 | 0:0 | 2:1 | 1:0 |
| 80-90 | 5:12 | 3:0 | 0:0 | 0:0 | 2:0 | 39:10 | 2:0 | 11:20 | 2:0 |
| 90-100 | 5:15 | 2:8 | 0:0 | 0:0 | 1:3 | 51:42 | 6:0 | 26:76 | 0:1 |
| 100-110 | 4:27 | 7:24 | 0:0 | 0:0 | 2:2 | 62:68 | 25:0 | 35:92 | 0:0 |
| 110-120 | 3:41 | 5:44 | 0:0 | 0:0 | 0:3 | 47:66 | 31:2 | 24:42 | 0:0 |
| 120-130 | 6:67 | 5:38 | 0:0 | 0:0 | 0:1 | 49:100 | 8:0 | 7:16 | 0:0 |
| 130-140 | 8:100 | 21:94 | 0:0 | 0:0 | 0:0 | 55:78 | 0:0 | 5:5 | 0:0 |
| 140-150 | 16:125 | 51:116 | 0:0 | 0:0 | 0:0 | 22:66 | 0:0 | 2:1 | 0:0 |
| 150-160 | 27:189 | 44:80 | 0:0 | 0:0 | 0:0 | 4:20 | 0:0 | 0:0 | 0:0 |
| 160-170 | 16:140 | 23:24 | 0:0 | 0:0 | 0:0 | 1:0 | 0:0 | 0:0 | 0:0 |
| 170-180 | 4:16 | 1:2 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 |
| 180-190 | 0:4 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 |
| 190-200 | 1:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 | 0:0 |

| SL bin | Sta 184 |
|---|---|
| 0-10 | 0:0 |
| 10-20 | 0:0 |
| 20-30 | 0:0 |
| 30-40 | 0:0 |
| 40-50 | 0:0 |
| 50-60 | 1:0 |
| 60-70 | 1:0 |
| 70-80 | 0:0 |
| 80-90 | 1:0 |
| 90-100 | 0:0 |
| 100-110 | 0:0 |
| 110-120 | 0:0 |
| 120-130 | 0:0 |
| 130-140 | 0:0 |
| 140-150 | 0:0 |
| 150-160 | 0:0 |

| | |
|---|---|
| 160-170 | 0:0 |
| 170-180 | 0:0 |
| 180-190 | 0:0 |
| 190-200 | 0:0 |

Table 14: Results from generalized additive model fits to selectivity data for the MCD survey. The response variable is number of surfclams caught in the survey dredge (a modified commercial dredge) compared to the number of surfclams caught in a lined dredge. The predictors are length bin (L), and a year−station (YrSta) effect. Some models included an offset based on the tow distance at each station. The s indicates a spline function and RE indicates random effects. The best model by AIC included random effects for each year−station combination in both intercept and length.

| Model | AIC | BIC |
|---|---|---|
| s(L)+s(YrSta,RE)+s(YrSta,L,RE) | 3228 | 3641 |
| s(L)+s(YrSta,RE) | 3602 | 3850 |
| s(L) | 7103 | 7143 |

Table 15: The MCD survey dredge (post 2011) selectivity coefficients estimated using the best (by AIC) selectivity model, by size bin.

| Length | Selx | uci | lci | Length | Selx | uci | lci |
|---|---|---|---|---|---|---|---|
| 5 | 0.043 | 0.612 | 0.001 | 101 | 0.786 | 0.806 | 0.765 |
| 7 | 0.038 | 0.503 | 0.001 | 103 | 0.804 | 0.822 | 0.784 |
| 9 | 0.033 | 0.397 | 0.002 | 105 | 0.818 | 0.835 | 0.799 |
| 11 | 0.029 | 0.303 | 0.002 | 107 | 0.828 | 0.844 | 0.811 |
| 13 | 0.025 | 0.227 | 0.002 | 109 | 0.836 | 0.852 | 0.819 |
| 15 | 0.022 | 0.169 | 0.003 | 111 | 0.842 | 0.858 | 0.826 |
| 17 | 0.020 | 0.127 | 0.003 | 112 | 0.847 | 0.862 | 0.830 |
| 18 | 0.018 | 0.098 | 0.003 | 114 | 0.850 | 0.866 | 0.833 |
| 20 | 0.017 | 0.077 | 0.003 | 116 | 0.853 | 0.869 | 0.835 |
| 22 | 0.016 | 0.062 | 0.004 | 118 | 0.855 | 0.871 | 0.836 |
| 24 | 0.015 | 0.051 | 0.004 | 120 | 0.856 | 0.874 | 0.838 |
| 26 | 0.014 | 0.044 | 0.005 | 122 | 0.858 | 0.876 | 0.838 |
| 28 | 0.014 | 0.039 | 0.005 | 124 | 0.860 | 0.879 | 0.839 |
| 30 | 0.014 | 0.035 | 0.005 | 126 | 0.862 | 0.881 | 0.841 |
| 32 | 0.014 | 0.032 | 0.006 | 128 | 0.865 | 0.885 | 0.843 |
| 34 | 0.014 | 0.030 | 0.006 | 130 | 0.868 | 0.888 | 0.845 |
| 36 | 0.014 | 0.029 | 0.007 | 132 | 0.871 | 0.892 | 0.847 |
| 38 | 0.015 | 0.029 | 0.008 | 134 | 0.874 | 0.896 | 0.850 |
| 40 | 0.016 | 0.028 | 0.009 | 136 | 0.878 | 0.899 | 0.852 |
| 41 | 0.017 | 0.029 | 0.009 | 137 | 0.881 | 0.903 | 0.855 |
| 43 | 0.018 | 0.030 | 0.010 | 139 | 0.885 | 0.907 | 0.858 |
| 45 | 0.019 | 0.031 | 0.011 | 141 | 0.888 | 0.910 | 0.860 |
| 47 | 0.020 | 0.032 | 0.013 | 143 | 0.890 | 0.913 | 0.862 |
| 49 | 0.022 | 0.034 | 0.014 | 145 | 0.892 | 0.916 | 0.864 |
| 51 | 0.024 | 0.037 | 0.016 | 147 | 0.894 | 0.918 | 0.864 |
| 53 | 0.026 | 0.040 | 0.017 | 149 | 0.895 | 0.919 | 0.864 |
| 55 | 0.029 | 0.043 | 0.020 | 151 | 0.895 | 0.920 | 0.863 |
| 57 | 0.033 | 0.048 | 0.022 | 153 | 0.895 | 0.921 | 0.861 |
| 59 | 0.037 | 0.053 | 0.026 | 155 | 0.894 | 0.921 | 0.859 |
| 61 | 0.043 | 0.060 | 0.030 | 157 | 0.892 | 0.921 | 0.856 |
| 63 | 0.049 | 0.068 | 0.036 | 159 | 0.890 | 0.920 | 0.852 |
| 64 | 0.058 | 0.078 | 0.043 | 160 | 0.888 | 0.919 | 0.847 |
| 66 | 0.069 | 0.091 | 0.051 | 162 | 0.885 | 0.918 | 0.842 |
| 68 | 0.083 | 0.108 | 0.063 | 164 | 0.882 | 0.916 | 0.836 |
| 70 | 0.100 | 0.128 | 0.078 | 166 | 0.879 | 0.915 | 0.831 |
| 72 | 0.122 | 0.154 | 0.096 | 168 | 0.877 | 0.914 | 0.825 |
| 74 | 0.150 | 0.185 | 0.120 | 170 | 0.874 | 0.914 | 0.821 |
| 76 | 0.184 | 0.223 | 0.150 | 172 | 0.873 | 0.914 | 0.816 |
| 78 | 0.225 | 0.267 | 0.187 | 174 | 0.872 | 0.914 | 0.813 |
| 80 | 0.272 | 0.317 | 0.232 | 176 | 0.872 | 0.915 | 0.812 |
| 82 | 0.326 | 0.372 | 0.284 | 178 | 0.874 | 0.918 | 0.811 |
| 84 | 0.385 | 0.431 | 0.341 | 180 | 0.876 | 0.920 | 0.812 |
| 86 | 0.446 | 0.490 | 0.402 | 182 | 0.879 | 0.924 | 0.813 |
| 88 | 0.506 | 0.548 | 0.464 | 183 | 0.884 | 0.929 | 0.815 |
| 89 | 0.564 | 0.603 | 0.523 | 185 | 0.888 | 0.934 | 0.818 |
| 91 | 0.616 | 0.652 | 0.579 | 187 | 0.894 | 0.940 | 0.820 |

*Continued*

Table 15: Table 15 Continued

| Length | Selx | uci | lci | Length | Selx | uci | lci |
|---|---|---|---|---|---|---|---|
| 93 | 0.663 | 0.695 | 0.629 | 189 | 0.900 | 0.946 | 0.823 |
| 95 | 0.703 | 0.732 | 0.673 | 191 | 0.906 | 0.952 | 0.825 |
| 97 | 0.737 | 0.762 | 0.710 | 193 | 0.912 | 0.957 | 0.827 |
| 99 | 0.764 | 0.786 | 0.740 | 195 | 0.918 | 0.963 | 0.828 |

Table 16: Results from model fits to predict meat weight. Predictors are ln(shell length) (L), ln(depth) (D), density ($\rho$), and region (R). Random effects are enclosed in parentheses and are limited to station (St), year (both affecting the estimate of the intercept), and length (affecting the estimate of the length coefficient). Regional coefficients are shown. SVA is assumed to have coefficient equal to 0.

| Formula | int | L | D | $\rho$ | R | AIC | BIC |
|---|---|---|---|---|---|---|---|
| L+D+(L+St)+(L+Year) | -8.05 (0.028) | 2.67 (0.042) | -0.08 (0.017) | | | 35383 | 35439 |
| L+(L+St)+(L+Year) | -8.36 (0.025) | 2.67 (0.042) | | | | 35404 | 35454 |
| L+Density+(L+St) | -8.45 (0.006) | 2.7 (0.022) | | -0.02 (0.004) | | 35473 | 35511 |
| L+(L+St) | -8.47 (0.006) | 2.69 (0.022) | | | | 35492 | 35523 |
| L+D+(L+St) | -8.47 (0.006) | 2.69 (0.022) | -0.03 (0.017) | | | 35492 | 35529 |
| L+D+(St) | -8.41 (0.006) | 2.7 (0.01) | -0.03 (0.017) | | | 36352 | 36377 |
| L+(St) | -8.51 (0.006) | 2.7 (0.01) | | | | 36353 | 36372 |

Table 16: Number of age samples in NEFSC clam surveys by survey year and region.

| Year | SVAtoSNE | GBK |
|---|---|---|
| 1982 | 1320 | 565 |
| 1983 | 1516 | 295 |
| 1984 | 0 | 170 |
| 1986 | 1602 | 792 |
| 1989 | 678 | 172 |
| 1992 | 400 | 376 |
| 1994 | 256 | 46 |
| 1997 | 262 | 103 |
| 1999 | 601 | 346 |
| 2002 | 811 | 164 |
| 2005 | 385 | 84 |
| 2008 | 669 | 146 |
| 2011 | 355 | 69 |
| 2012 | 284 | 0 |
| 2013 | 35 | 55 |
| 2014 | 4 | 38 |
| 2015 | 650 | 0 |
| 2016 | 16 | 248 |
| 2018 | 663 | 0 |

Table 17: Growth curve (Von Bertalanffy) parameter estimates and standard errors for each region by year. Year and region combinations that did not provide sufficient data for model convergence are not shown. SVAtoSNE is the southern area and GBK is the northern area.

| Region | Year | n | $L_\infty$ | $L_\infty se$ | K | K se | $t_0$ | $t_0 se$ |
|---|---|---|---|---|---|---|---|---|
| SVAtoSNE | 1982 | 1320 | 168.7 | 1.03 | 0.268 | 0.008 | -0.222 | 0.089 |
| SVAtoSNE | 1983 | 1516 | 172.4 | 1.04 | 0.259 | 0.008 | -0.213 | 0.094 |
| SVAtoSNE | 1986 | 1602 | 175.3 | 1.35 | 0.184 | 0.007 | -0.799 | 0.147 |
| SVAtoSNE | 1989 | 678 | 162.4 | 1.68 | 0.251 | 0.014 | 0.104 | 0.156 |
| SVAtoSNE | 1992 | 400 | 165.1 | 2.27 | 0.207 | 0.015 | -0.674 | 0.229 |
| SVAtoSNE | 1994 | 256 | 166.9 | 4.09 | 0.162 | 0.021 | -1.300 | 0.583 |
| SVAtoSNE | 1997 | 262 | 169.0 | 2.38 | 0.185 | 0.016 | -0.894 | 0.324 |
| SVAtoSNE | 1999 | 601 | 162.3 | 1.28 | 0.261 | 0.013 | -0.311 | 0.152 |
| SVAtoSNE | 2002 | 811 | 167.2 | 1.93 | 0.192 | 0.013 | -1.346 | 0.245 |
| SVAtoSNE | 2005 | 385 | 163.8 | 3.46 | 0.155 | 0.016 | -1.659 | 0.498 |
| SVAtoSNE | 2008 | 669 | 156.4 | 1.60 | 0.222 | 0.013 | -0.801 | 0.182 |
| SVAtoSNE | 2011 | 285 | 156.8 | 2.97 | 0.180 | 0.020 | -1.361 | 0.475 |
| SVAtoSNE | 2012 | 268 | 163.8 | 4.37 | 0.137 | 0.022 | -3.618 | 0.967 |
| SVAtoSNE | 2015 | 580 | 158.8 | 3.43 | 0.119 | 0.015 | -4.048 | 0.763 |
| SVAtoSNE | 2018 | 665 | 161.4 | 3.05 | 0.120 | 0.011 | -2.887 | 0.583 |
| GBK | 1982 | 565 | 175.8 | 2.49 | 0.181 | 0.010 | -0.879 | 0.176 |
| GBK | 1983 | 295 | 169.1 | 4.58 | 0.237 | 0.026 | -0.209 | 0.295 |
| GBK | 1984 | 170 | 234.5 | 25.11 | 0.113 | 0.023 | -0.423 | 0.297 |
| GBK | 1986 | 792 | 166.2 | 2.86 | 0.182 | 0.010 | -0.387 | 0.147 |
| GBK | 1989 | 172 | 149.4 | 3.31 | 0.245 | 0.035 | -0.173 | 0.470 |
| GBK | 1992 | 376 | 148.5 | 2.52 | 0.264 | 0.020 | 0.400 | 0.170 |
| GBK | 1994 | 46 | 145.5 | 4.49 | 0.300 | 0.075 | 1.224 | 0.761 |
| GBK | 1997 | 103 | 140.5 | 3.79 | 0.226 | 0.035 | -0.449 | 0.442 |
| GBK | 1999 | 346 | 133.9 | 1.55 | 0.388 | 0.030 | 0.083 | 0.185 |
| GBK | 2002 | 164 | 146.3 | 5.74 | 0.200 | 0.037 | -1.169 | 0.577 |
| GBK | 2005 | 84 | 138.0 | 1.85 | 0.291 | 0.027 | -0.152 | 0.173 |
| GBK | 2008 | 146 | 145.4 | 3.10 | 0.224 | 0.028 | -0.953 | 0.368 |
| GBK | 2011 | 148 | 145.7 | 2.22 | 0.275 | 0.026 | -0.405 | 0.226 |
| GBK | 2012 | 28 | 151.6 | 6.85 | 0.247 | 0.057 | -1.054 | 0.702 |
| GBK | 2013 | 58 | 136.3 | 3.93 | 0.429 | 0.143 | 0.986 | 0.862 |
| GBK | 2015 | 65 | 165.9 | 13.52 | 0.119 | 0.031 | -2.984 | 0.946 |
| GBK | 2016 | 256 | 149.3 | 1.78 | 0.289 | 0.033 | -0.036 | 0.453 |
| GBK | 2019 | 209 | 152.9 | 1.94 | 0.370 | 0.043 | 1.261 | 0.320 |
| All | 1982 | 1885 | 169.9 | 0.99 | 0.240 | 0.007 | -0.391 | 0.083 |
| All | 1983 | 1811 | 172.4 | 1.06 | 0.251 | 0.008 | -0.241 | 0.092 |
| All | 1984 | 170 | 234.5 | 25.11 | 0.113 | 0.023 | -0.423 | 0.297 |
| All | 1986 | 2394 | 173.7 | 1.27 | 0.183 | 0.005 | -0.544 | 0.102 |
| All | 1989 | 850 | 159.1 | 1.52 | 0.252 | 0.014 | 0.054 | 0.156 |
| All | 1992 | 776 | 160.8 | 1.98 | 0.207 | 0.012 | -0.394 | 0.166 |
| All | 1994 | 302 | 161.1 | 3.20 | 0.185 | 0.022 | -0.811 | 0.505 |
| All | 1997 | 365 | 160.2 | 2.15 | 0.207 | 0.016 | -0.529 | 0.265 |

*Continued*

Table 17: Table 17 Continued

| Region | Year | n | $L_\infty$ | $L_\infty se$ | K | K se | $t_0$ | $t_0 se$ |
|---|---|---|---|---|---|---|---|---|
| All | 1999 | 947 | 152.2 | 1.08 | 0.303 | 0.014 | -0.080 | 0.129 |
| All | 2002 | 975 | 166.4 | 2.16 | 0.173 | 0.012 | -1.718 | 0.263 |
| All | 2005 | 469 | 156.1 | 2.30 | 0.189 | 0.014 | -0.915 | 0.267 |
| All | 2008 | 815 | 154.6 | 1.44 | 0.224 | 0.012 | -0.801 | 0.162 |
| All | 2011 | 433 | 152.3 | 1.95 | 0.209 | 0.015 | -0.943 | 0.247 |
| All | 2012 | 296 | 161.9 | 3.61 | 0.151 | 0.021 | -3.043 | 0.745 |
| All | 2013 | 58 | 136.3 | 3.93 | 0.429 | 0.143 | 0.986 | 0.862 |
| All | 2015 | 645 | 157.4 | 2.88 | 0.129 | 0.013 | -3.452 | 0.582 |
| All | 2016 | 256 | 149.3 | 1.78 | 0.289 | 0.033 | -0.036 | 0.453 |
| All | 2018 | 665 | 161.4 | 3.05 | 0.120 | 0.011 | -2.887 | 0.583 |
| All | 2019 | 209 | 152.9 | 1.94 | 0.370 | 0.043 | 1.261 | 0.320 |

Table 18: Numbers of successful random survey tows with sensor data. Tows are shown in the year they were made (with no borrowing).

| Year | South | North |
|---|---|---|
| 1997 | 232 | 57 |
| 1999 | 219 | 33 |
| 2002 | 228 | 21 |
| 2005 | 189 | 0 |
| 2008 | 208 | 36 |
| 2011 | 186 | 78 |
| 2012 | 121 | 0 |
| 2013 | 14 | 68 |
| 2014 | 2 | 19 |
| 2015 | 146 | 0 |
| 2016 | 8 | 125 |
| 2018 | 178 | 0 |

Table 19: Models relating the proportion of positive tows in the survey to year and stratum used to evaluate the precision of the MCD survey, where $C_t$ is catch in tow $t$, $yr$ is year as a factor, and $str$ is the stratum.

| Model | Formula | Family | Link | df | AIC |
|---|---|---|---|---|---|
| glmA | $C_t = yr$ | Tweedie(p=1.7) | log | 9 | 14,060 |
| glmB | $C_t = str$ | Tweedie(p=1.7)) | log | 31 | 13,923 |
| gamA | $C_t = s(yr, by = str)$ | Tweedie(p=1.7) | log | 67 | 14,160 |
| gamB | $C_t = s(yr, by = str) + str$ | Tweedie(p=1.7) | log | 118 | 13,495 |

Table 20: Structure of SS3 models used for surfclams in the southern and northern areas.

| Model aspect | South | North | Note |
|---|---|---|---|
| $M$ | 0.15 | 0.15 | Constant for all ages and years |
| Age bins | 0–30 | 0–30 | |
| Length bins | 1–20 cm | 1–20 cm | |
| Time | 1965–2019 | 1984–2019 | |
| Seasons/morphs/subareas | 1/1/1 | 1/1/1 | 1 season, 2 Growth patterns, 2 areas |
| Commercial fleets | 1 | 1 | |
| Fishery selectivity | Double normal | Double normal | |
| Surveys (trend) | 2 | 2 | RD (trend) RD-SWAN (scale) MCD (scale and trend) |
| Survey selectivity RD | Double normal | Double normal | Estimated |
| Survey selectivity MCD | Double normal | Double normal | Estimated |
| Survey catchability (RD-SWAN) | Estimated | Estimated | Uses informative prior distribution |
| Survey catchability (MCD) | Estimated | Estimated | Uses informative prior distribution |
| Recruitment Model | Beverton-Holt | Beverton-Holt | Fixed steepness, estimated $R_0$ and variance; random walk determines proportion of recruits going to each area |
| Recruit dev years | 1965–2019 | 1969–2019 | |
| Bias Adjustment parameters | 1955,1976,2008,2015,0.79 | 1961,1974,2006,2015,0.87 | |
| $F$ method | Hybrid | Hybrid | 6 iterations (exact F) |

Table 21: Parameters estimated internally and externally in SS3 base models for Atlantic surfclam. Parameters listed as fixed or estimated apply to both areas. Parameters listed as estimated in one area are fixed in the other. Numbers of parameters are summarized in the last rows.

| Parameter | South | North | Note |
|---|---|---|---|
| $M$ | 0.15 | 0.15 | Fixed |
| Length at age 4 | 9.803 | 9.588 | Estimated |
| Length at age 30 | 17.268 | 14.707 | Estimated (both) and time varying in South |
| Von Bertalanffy $K$ | 0.153 | 0.245 | Estimated |
| CV of size at ages 5 y | 0.189 | 0.208 | Estimated |
| CV of size at age 30 y | 0.079 | 0.079 | Estimated |
| Shell length to meat weight multiplier | 9e-05 | 0.00011 | Fixed |
| Shell length to meat weight exponent | 2.733 | 2.733 | Fixed |
| Spawner recruit $R_0$ | 15.191 | 15.191 | Estimated |
| Spawner recruit steepness | 0.95 | 0.95 | Fixed |
| Spawner recruit sd | 0.478 | 0.478 | Estimated |
| Catchability RD | 0.232 | 0.587 | Estimated (with prior) |
| Catchability MCD | 0.631 | 0.695 | Estimated (with prior) |
| Fishery selectivity peak | 15.729 | 13.751 | Estimated |
| Fishery selectivity top | -4.0219 | -8.81749 | Estimated |
| Fishery selectivity asc. width | 1.909 | 1.546 | Estimated |
| Fishery selectivity dec. width | -1.03527 | 1.218 | Estimated |
| Fishery selectivity init | -495 | -495 | Estimated (with prior) |
| Fishery selectivity final | -0.97499 | -450 | Estimated (with prior) |
| Survey (RD) selectivity Peak | 13.482 | 11.892 | Estimated |
| Survey (RD) selectivity top | -4.09739 | -0.64891 | Estimated |
| Survey (RD) selectivity asc. width | 3.588 | 3.123 | Estimated |
| Survey (RD) selectivity dec. width | 2.667 | 2.356 | Estimated |
| Survey (RD) selectivity init | -4.87001 | -999 | Estimated (with prior) |
| Survey (RD) selectivity final | -1.86012 | -0.81743 | Estimated (with prior) |
| Survey (MCD) selectivity Peak | 12.8 | 13.523 | Estimated |
| Survey (MCD) selectivity top | 0.05 | -2.98899 | Estimated |
| Survey (MCD) selectivity asc. width | 2.565 | 2.23 | Estimated |
| Survey (MCD) selectivity dec. width | 2.506 | 1.456 | Estimated |
| Survey (MCD) selectivity init | -499.5 | -4.79747 | Estimated (with prior) |
| Survey (MCD) selectivity final | -0.00069 | -3.41049 | Estimated (with prior) |
| Initial F | 0.014 | 0.0 | Estimated in South |
| Total estimated (-recruit deviations) | 183 | | |
| Recruit deviations | 57 | | |
| Total estimated | 240 | | |

Table 22: Parameter estimates and estimated precision in a basecase model run for Atlantic surfclam. This table shows the thirty parameters that are the least precisely determined, ranked by coefficient of variation.

| name | value | std.dev | cv |
|---|---|---|---|
| parm_dev[1] | -0.00 | 0.69 | 3583.65 |
| Fcast_recruitments | -0.00 | 0.48 | 3293.96 |
| parm_dev[1] | 0.00 | 1.00 | 3154.62 |
| selparm[26] | -0.00 | 1.54 | 2250.99 |
| recdev1970 | -0.00 | 0.42 | 222.34 |
| parm_dev[1] | 0.00 | 0.88 | 218.89 |
| parm_dev[1] | 0.01 | 0.89 | 134.60 |
| parm_dev[1] | 0.01 | 1.00 | 72.97 |
| recdev2016 | 0.01 | 0.34 | 46.24 |
| recdev1999 | 0.01 | 0.25 | 32.45 |
| selparm[22] | 0.05 | 1.51 | 30.19 |
| selparm[12] | -450.00 | 12298.00 | 27.33 |
| selparm[5] | -495.00 | 11292.00 | 22.81 |
| selparm[11] | -495.00 | 11292.00 | 22.81 |
| recdev2010 | 0.01 | 0.28 | 22.21 |
| parm_dev[1] | 0.05 | 0.85 | 17.50 |
| recdev1968 | -0.03 | 0.44 | 15.70 |
| recdev1979 | 0.02 | 0.31 | 15.68 |
| recdev1994 | 0.03 | 0.44 | 13.72 |
| parm_dev[1] | 0.06 | 0.75 | 12.89 |
| parm_dev[1] | -0.07 | 0.90 | 12.78 |
| parm_dev[1] | 0.05 | 0.68 | 12.38 |
| parm_dev[1] | -0.08 | 0.88 | 11.58 |
| parm_dev[1] | -0.11 | 0.87 | 7.67 |
| recdev1971 | -0.06 | 0.42 | 6.87 |
| parm_dev[1] | -0.15 | 0.89 | 6.11 |
| parm_dev[1] | 0.13 | 0.77 | 5.92 |
| parm_dev[1] | 0.15 | 0.78 | 5.20 |
| recdev2013 | 0.07 | 0.34 | 5.15 |
| recdev1987 | 0.05 | 0.26 | 5.09 |

Table 23: Likelihood profile over unfished recruitment parameter (R0). The values in the table are the differences, in likelihood units, between each profile run and the minimum likelihood for that row (likelihood component). Conflicts within the data are apparent when the minimum likelihood values (gray cells) occur in different columns for each row. That is, different likelihood components within the model were minimized at different values of R0. Because R0 is important for setting the scale of estimated biomass in the model (Relative B; last row), data conflicts around R0 tend to increase uncertainty in scale. The coloumn corresponding to the minimum total likelihood is shown in italics.

| ln(R0) | 14.09 | 14.59 | 14.84 | 15.09 | 15.34 | 15.59 | 16.09 |
|---|---|---|---|---|---|---|---|
| TOTAL | 35.3 | 6.66 | 1.68 | 0 | 0.4 | 2.4 | 10.5 |
| Survey | 0 | 1.7 | 2.4 | 3.1 | 3.8 | 4.1 | 3.8 |
| Length comp | 4.8 | 0.5 | 0 | 0 | 0.4 | 1.3 | 4.3 |
| Age comp | 21.7 | 5.9 | 2.9 | 1.2 | 0.3 | 0 | 0.6 |
| Recruitment | 0 | 1.6 | 2 | 2.2 | 2.3 | 2.3 | 2.8 |
| Forecast Recruitment | 0 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Parm priors | 15.2 | 3.5 | 1 | 0 | 0.2 | 1 | 4.6 |
| Parm devs | 0.7 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0 |
| F Relative Ballpark | 0.2 | 0 | 0 | 0.2 | 0.3 | 0.6 | 1.3 |
| Relative B | 1 | 3.5 | 4.7 | 5.7 | 6.6 | 7.4 | 9.4 |

Table 24: Comparison of reference points estimated in an earlier assessment and from the current assessment update. The recommended $F$ reference point is based on an MSE analysis (?) and a previous assessment (Northeast Fisheries Science Center 2017a). MSY values are not based on per recruit modeling, but rather applying $F_{MSY}$ to the unfished biomass, while accounting for natural mortality. Biomass scale was highly uncertain in the previous assessment, which led to the recommendation of trend based reference points.

| | 2017 | 2020 |
|---|---|---|
| $F_{Threshold}$ | 0.019 | 0.141 (0.09 - 0.222) |
| $SSB_0$ ('000 mt) | 5377 | 2054 (1166 - 2941) |
| $SSB_{MSY}$ ('000 mt) | 2688 | 1027 (583 - 1470) |
| $SSB_{Threshold}$ ('000 mt) | 1344 | 513 (292 - 735) |
| *Overfishing* | No | No |
| *Overfished* | No | No |

Table 25: Spawning stock Atlantic surfclam fishing mortality status estimates (based on recommended reference points) with cv and approximate 95% confidence intervals.

| | Ratio | CV | LCI | UCI |
|---|---|---|---|---|
| $\frac{F_{2019}}{F_{Threshold}}$ | 0.258 | 0.251 | 0.159 | 0.419 |

Table 26: Spawning stock Atlantic surfclam biomass status estimates (based on recommended reference points) with cv and approximate 95% confidence intervals.

| | Ratio | CV | LCI | UCI |
|---|---|---|---|---|
| $\frac{SSB_{2019}}{SSB_{Threshold}}$ | 2.38 | 0.107 | 1.88 | 2.89 |

Table 27: Projected spawning stock biomass (mt) and biomass status ($\frac{SSB}{SSB_{Threshold}}$, where $SSB_{Threshold} = 0.25 * SSB_0$) during 2020-2026 for Atlantic surfclam.

| Year | Status Quo | Quota | OFL |
|---|---|---|---|
| | **SSB (mt)** | | |
| 2020 | 1123520 | 1123520 | 1123520 |
| 2021 | 1094560 | 1086910 | 1068770 |
| 2022 | 1084380 | 1069950 | 1038990 |
| 2023 | 1086030 | 1065650 | 1026010 |
| 2024 | 1090210 | 1064640 | 1019260 |
| 2025 | 1097710 | 1067750 | 1018210 |
| 2026 | 1107250 | 1073570 | 1020640 |
| | $\frac{SSB}{SSB_{Threshold}}$ | | |
| 2020 | 2.32 | 2.32 | 2.32 |
| 2021 | 2.26 | 2.24 | 2.21 |
| 2022 | 2.24 | 2.21 | 2.15 |
| 2023 | 2.24 | 2.20 | 2.12 |
| 2024 | 2.25 | 2.20 | 2.11 |
| 2025 | 2.27 | 2.21 | 2.10 |
| 2026 | 2.29 | 2.22 | 2.11 |

Table 28: Projected catch (landings + incidental mortality; mt) and fishing mortality status ratio $\frac{F}{F_{Threshold}}$ during 2020-2026 for Atlantic surfclam.

| Year | Status Quo | Quota | OFL |
|---|---|---|---|
| **Catch (mt)** | | | |
| 2020 | 19255 | 29364 | 55337 |
| 2021 | 19255 | 29364 | 51361 |
| 2022 | 19255 | 29364 | 48202 |
| 2023 | 19255 | 29364 | 45959 |
| 2024 | 19255 | 29364 | 44629 |
| 2025 | 19255 | 29364 | 44048 |
| 2026 | 19255 | 29364 | 43886 |
| $\frac{F}{F_{Threshold}}$ | | | |
| 2020 | 0.334 | 0.513 | 1.025 |
| 2021 | 0.346 | 0.535 | 1.025 |
| 2022 | 0.356 | 0.556 | 1.025 |
| 2023 | 0.364 | 0.573 | 1.025 |
| 2024 | 0.363 | 0.574 | 1.025 |
| 2025 | 0.356 | 0.563 | 1.025 |
| 2026 | 0.357 | 0.568 | 1.025 |

Table 29: Cumulative probability of being in overfished status in any of the years from 2020-2026 under a variety of catch scenarios for Atlantic surfclam.

| Catch scenario | $P[Overfished]$ | $P[Overfishing]$ |
|---|---|---|
| Status Quo | 0.065 | 0.000 |
| Quota | 0.086 | 0.000 |
| OFL | 0.104 | 0.646 |

Table 30: Estimated catch (landings + incidental mortality; mt) at the Overfishing Limit (OFL) from selected years between 2020-2026 for Atlantic surfclam.

| Year | Mean | Median | CV | LCI | UCI |
|---|---|---|---|---|---|
| 2020 | 57848 | 55309 | 0.31 | 32065 | 104363 |
| 2021 | 53929 | 51375 | 0.32 | 29244 | 99449 |
| 2022 | 50795 | 48233 | 0.33 | 26951 | 95735 |
| 2023 | 48554 | 45954 | 0.34 | 25346 | 93013 |
| 2024 | 47223 | 44639 | 0.35 | 24430 | 91283 |
| 2025 | 46612 | 44039 | 0.35 | 24070 | 90264 |

## 3 Figures

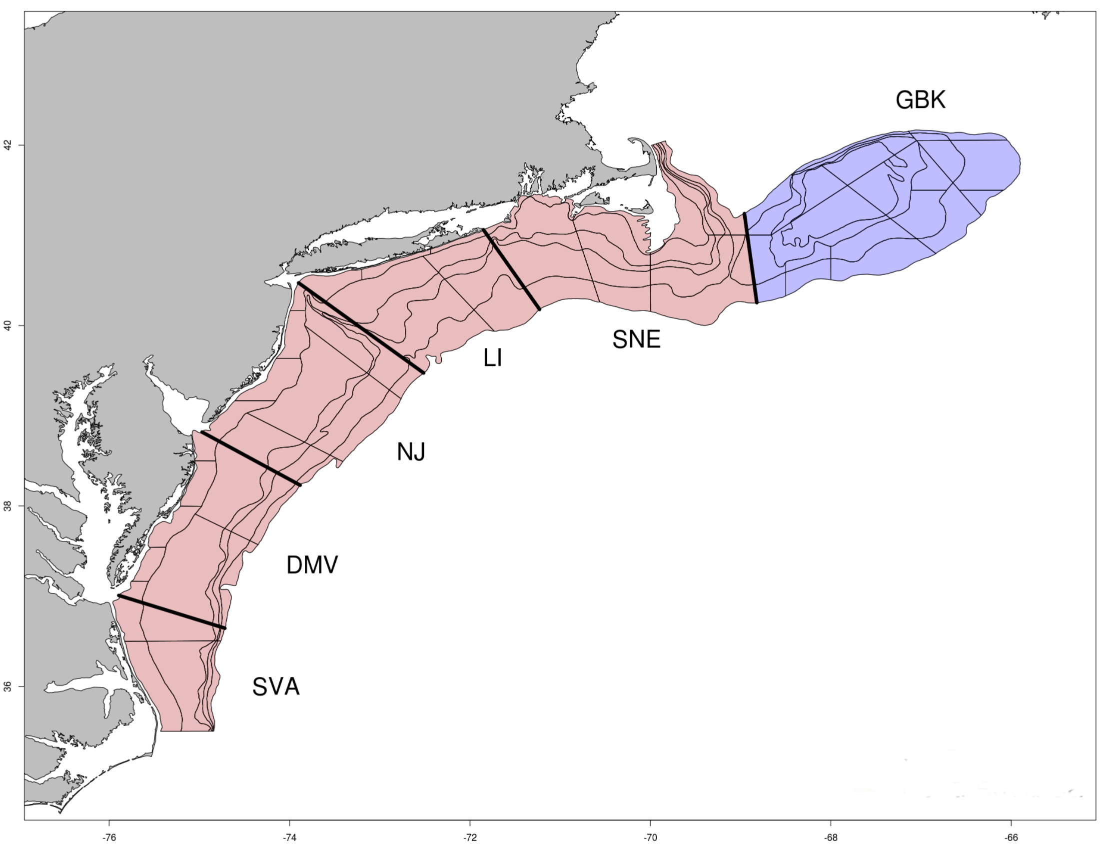



Figure 1: The Atlantic surfclam regions divided, for assessment modeling, into two areas. The northern area is blue and the southern area is pink.

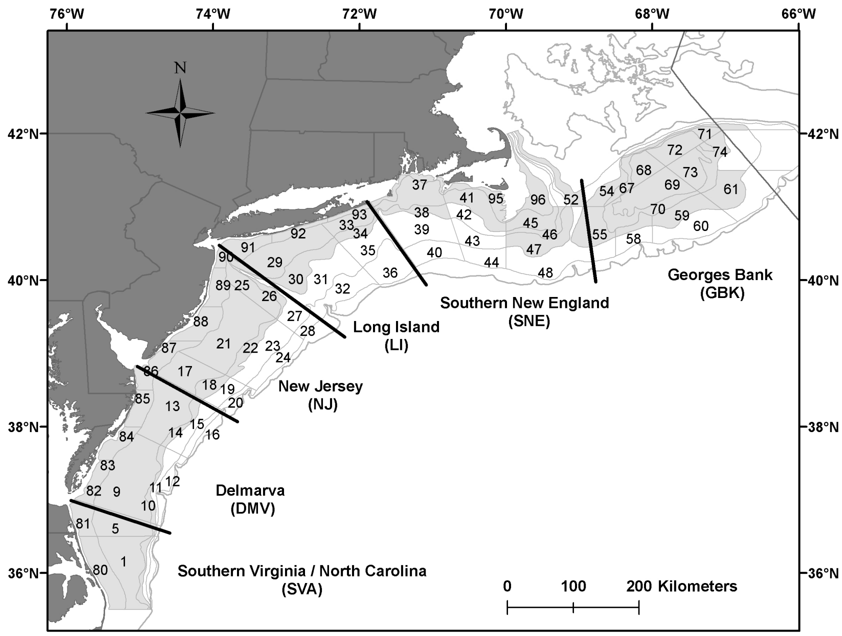



Figure 2: Surfclam stock assessment regions and NEFSC shellfish survey strata. The shaded strata are the surfclam strata that have been used in past assessments.

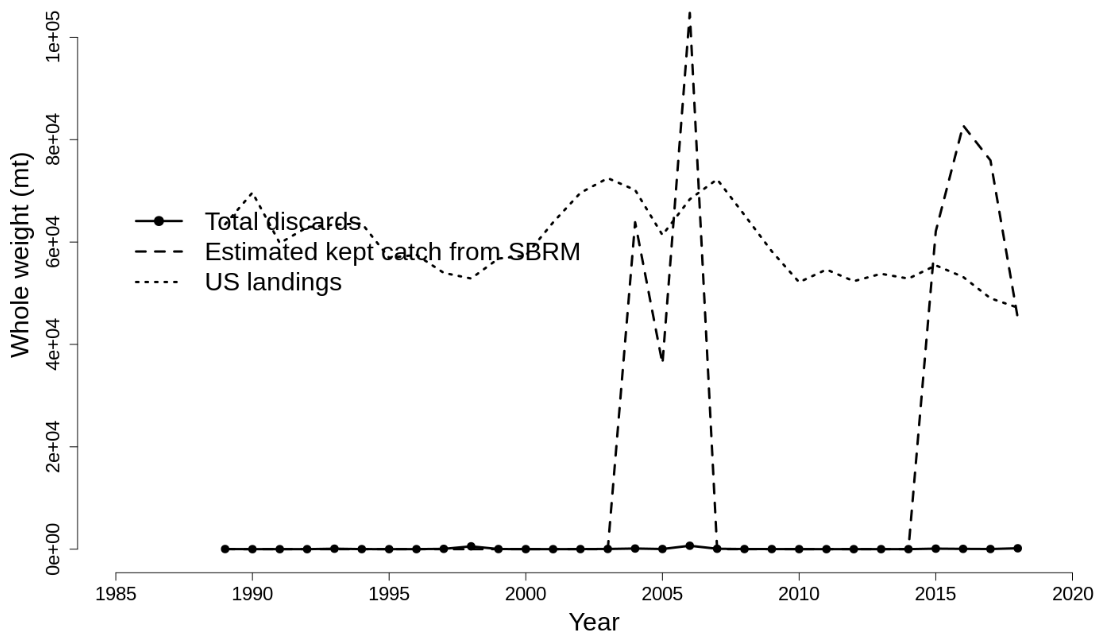



Figure 3: Total US discard estimates of Atlantic surfclam based on the Standardized Bycatch Reporting Methodology, total estimated 'kept' catch based on observed tows (not all years had observed clam tows), and total landings converted to whole weight using the median ratio of whole weight to meat weight from all years of the NEFSC survey.

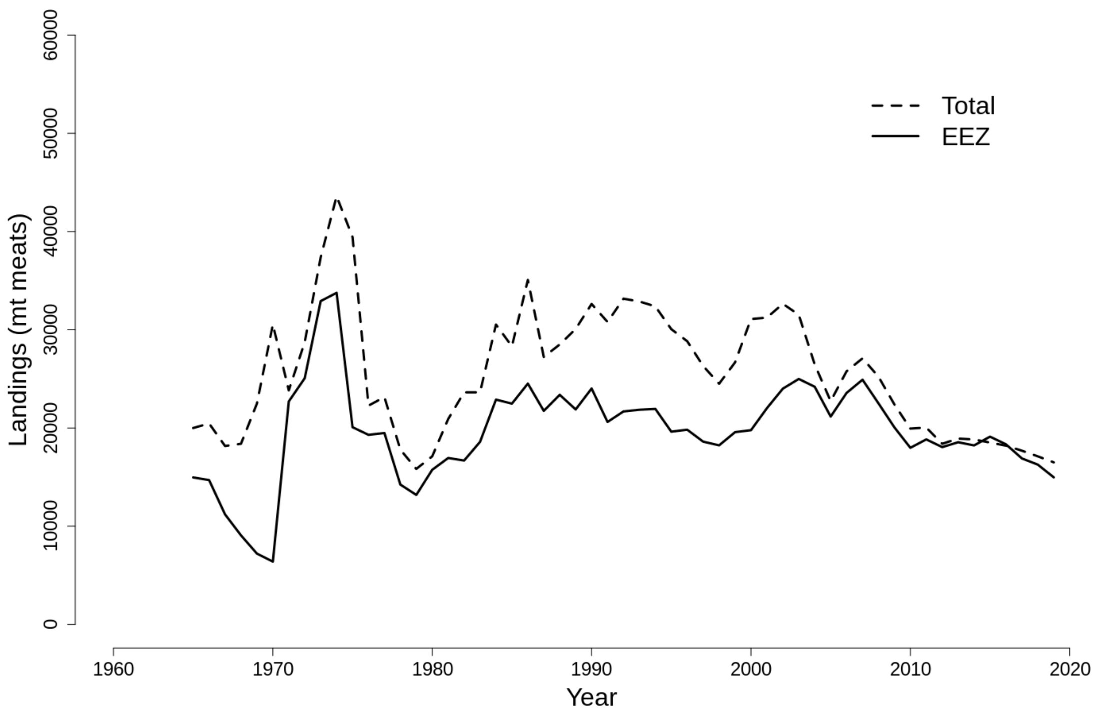



Figure 4: Atlantic surfclam landings (total and EEZ) during 1965-2019.

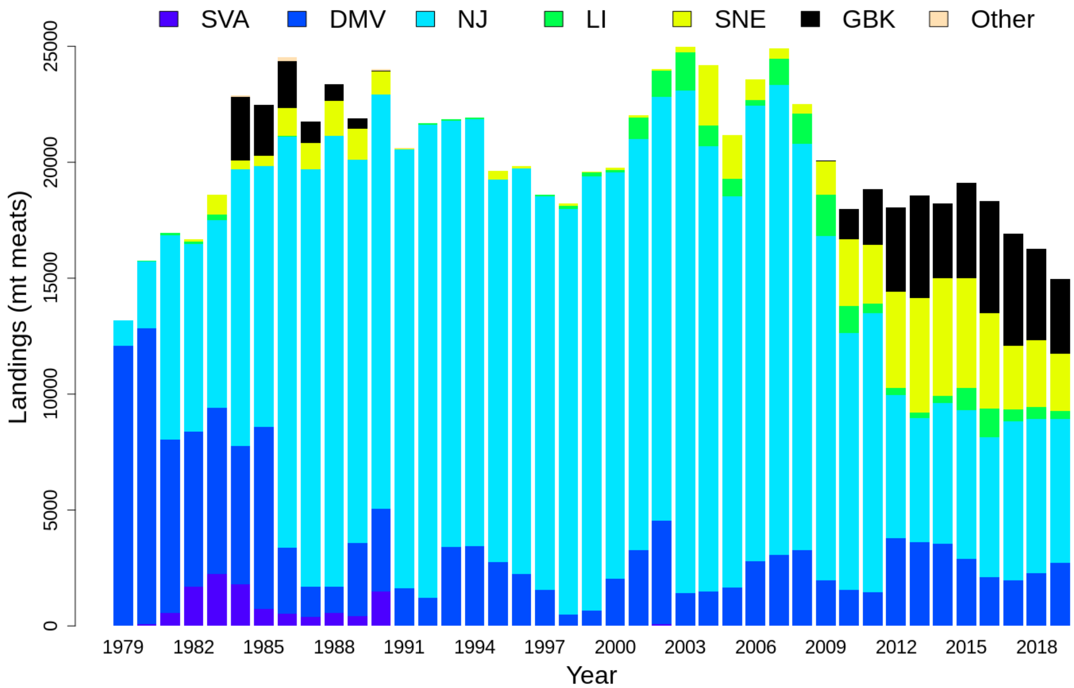



Figure 5: Surfclam landings from the US EEZ during 1979-2019, by stock assessment region.

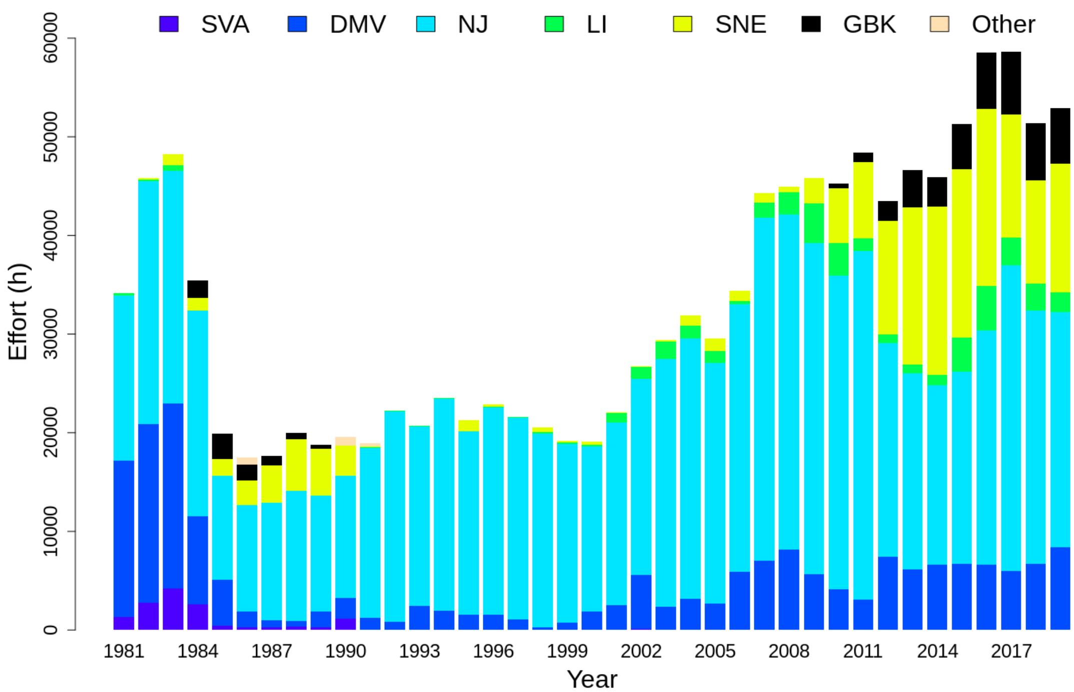



Figure 6: Surfclam hours fished from the US EEZ during 1981-2019, by stock assessment region.

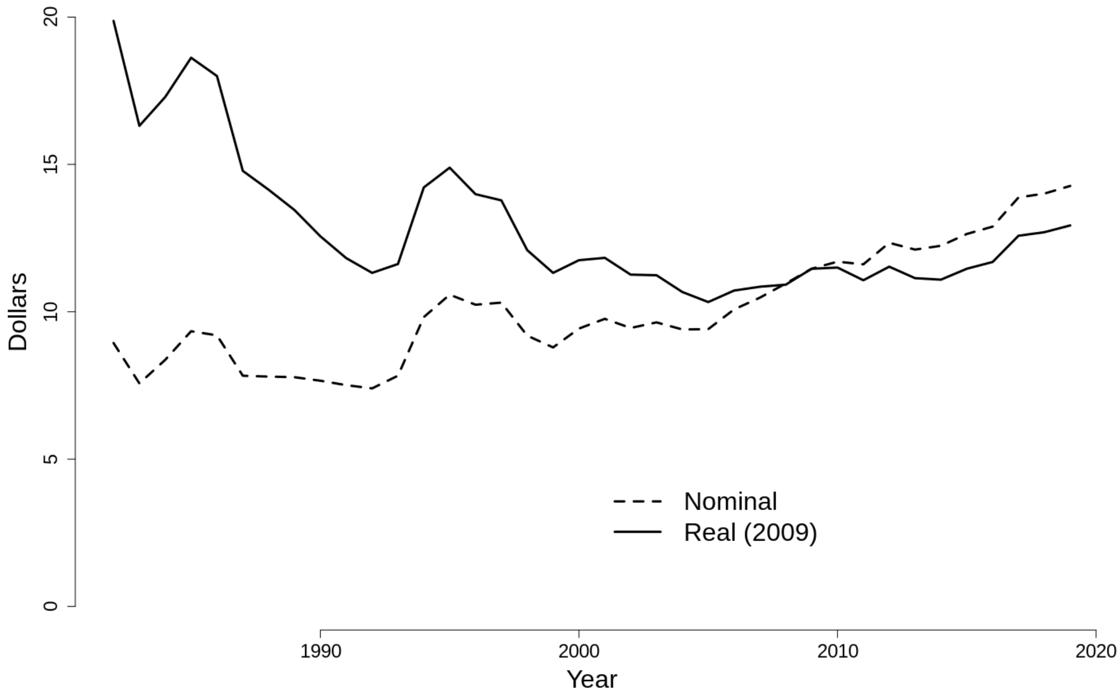



Figure 7: Nominal and 2009 dollar equivalent prices for surfclam 1981-2019.

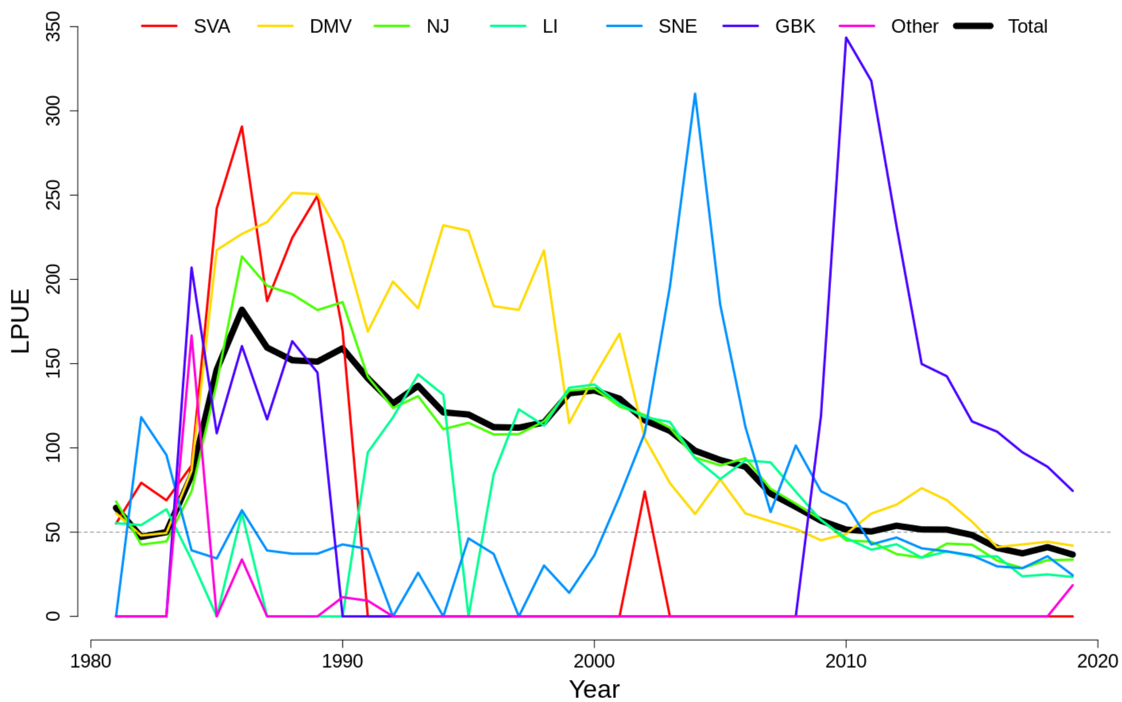



Figure 8: Nominal landings per unit effort (LPUE in bushels landed per hour fished) for surfclam, by region and overall. LPUE is total landings in bushels divided by total fishing effort. A dashed line has been added at LPUE=50 for reference.

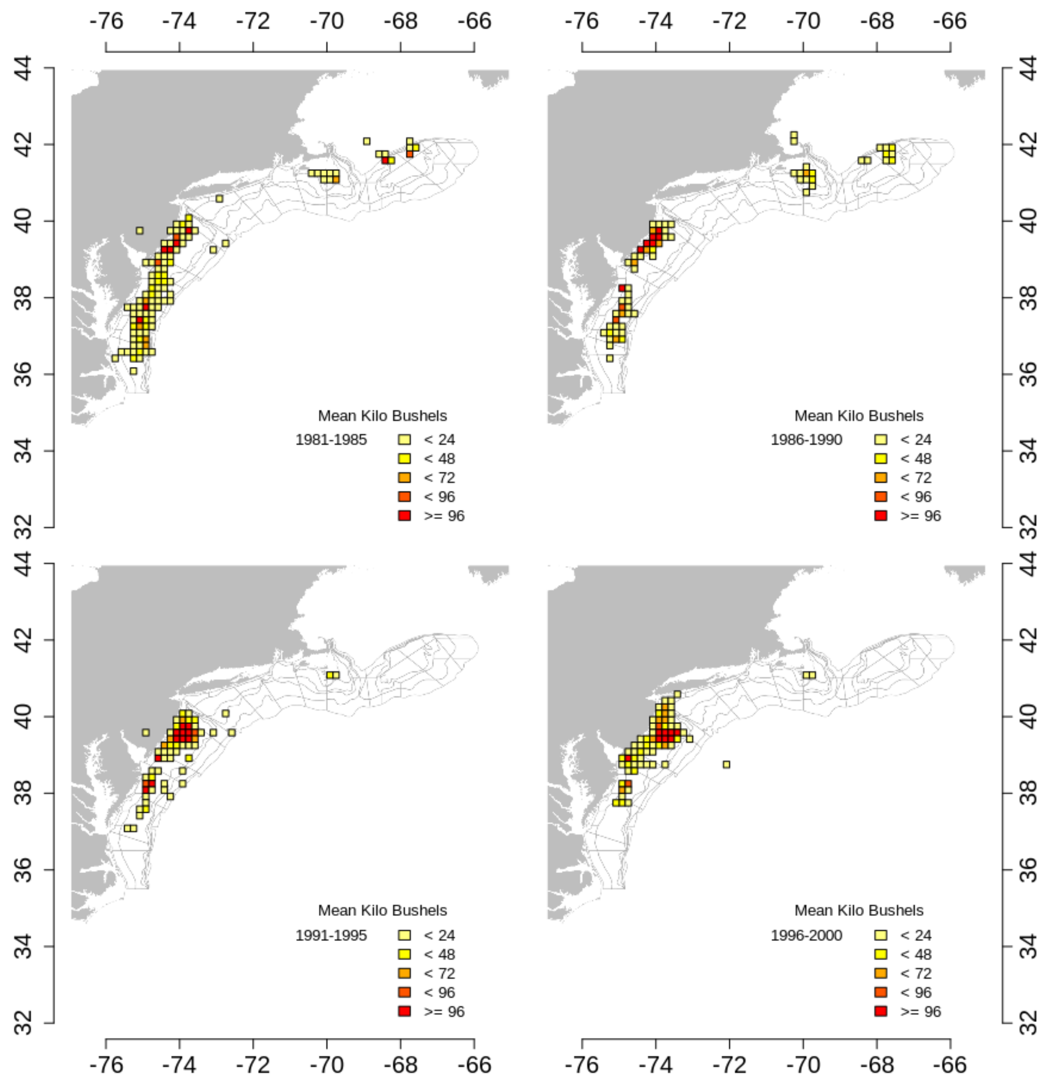



Figure 9: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

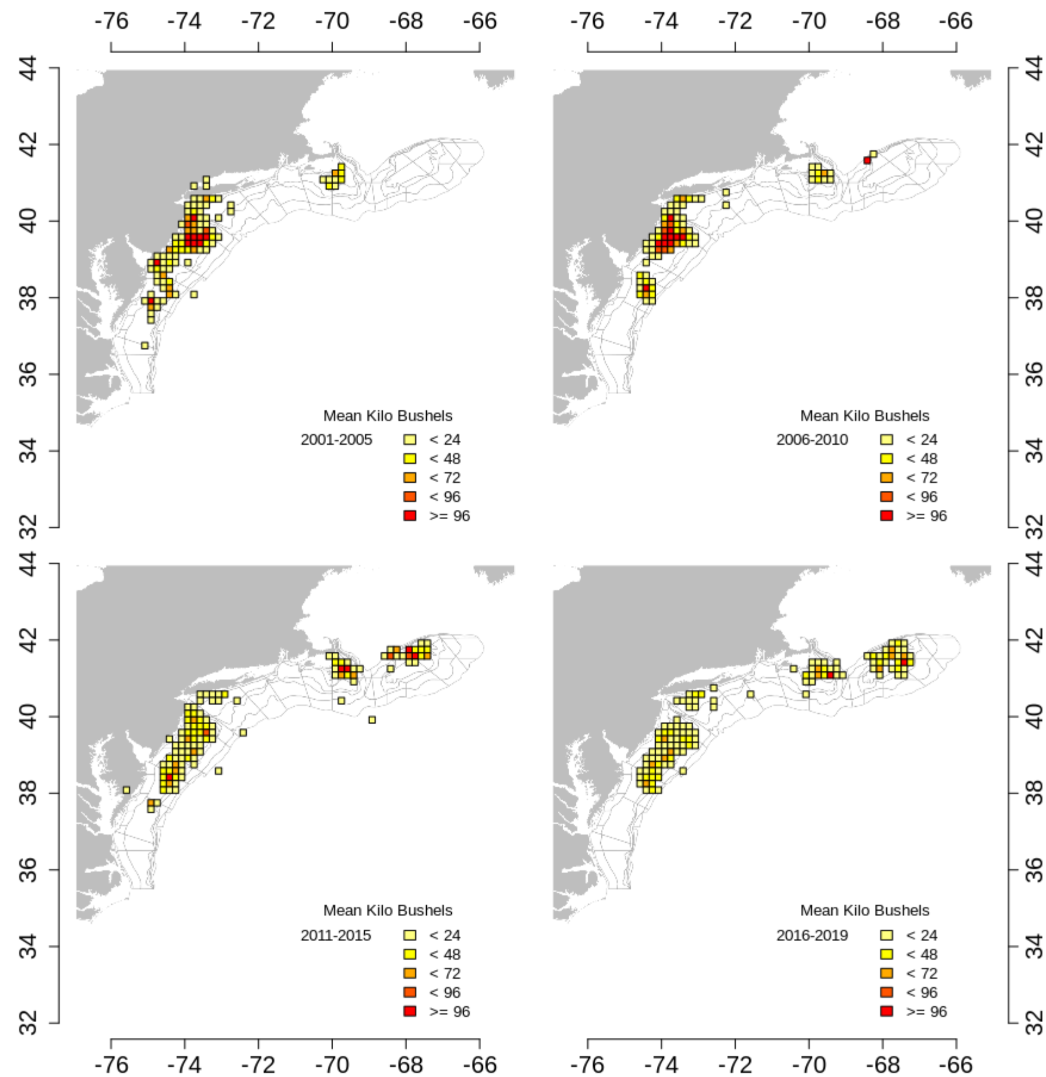



Figure 10: Average surfclam landings by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

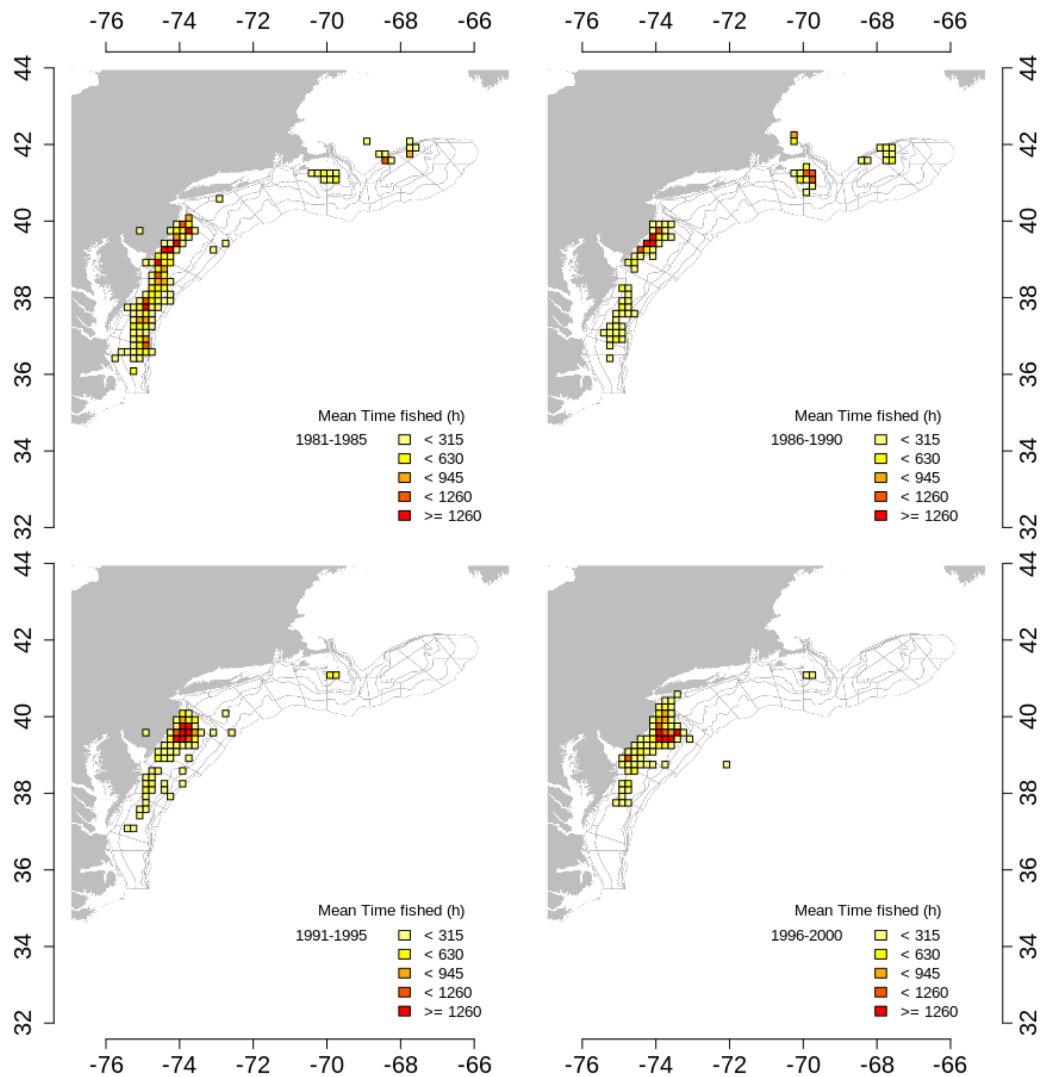



Figure 11: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

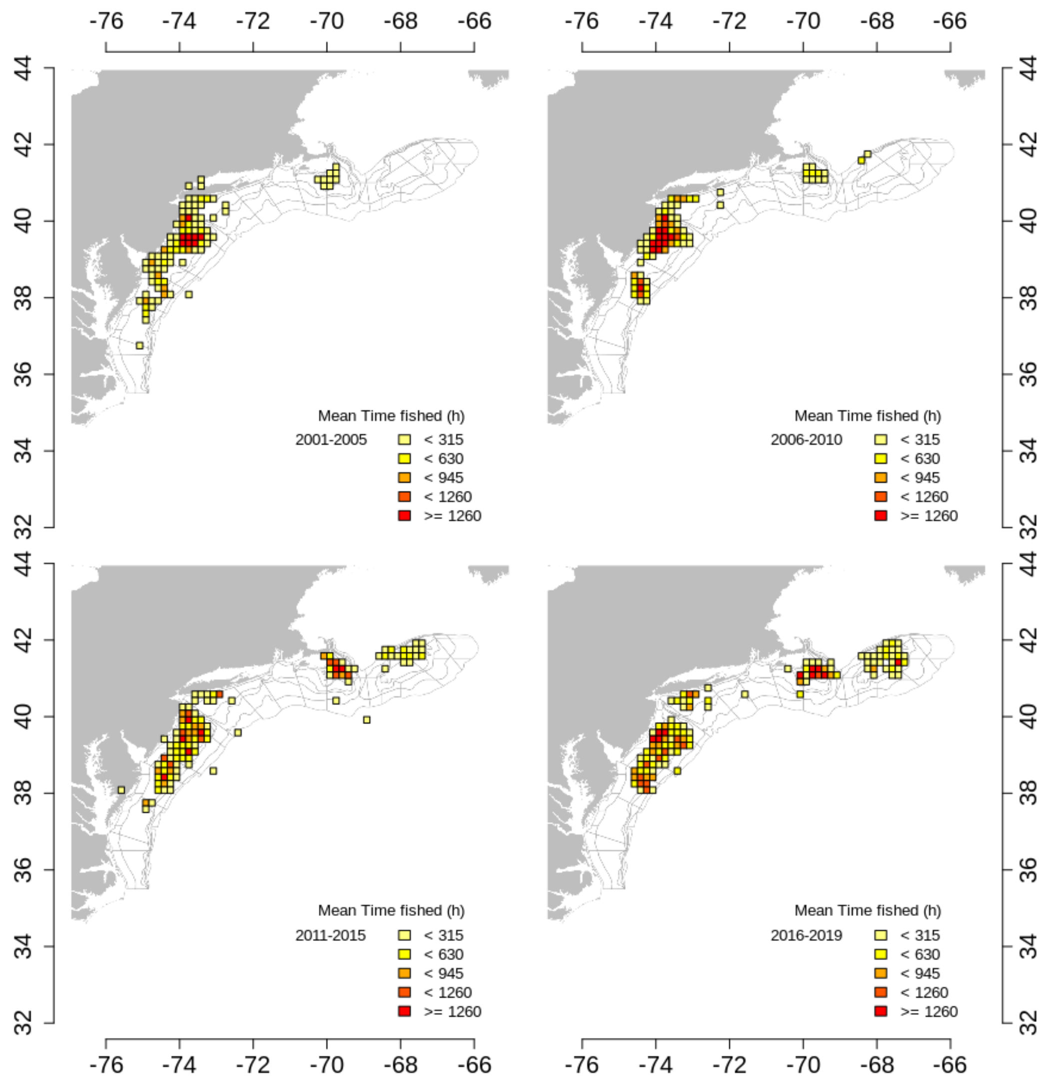



Figure 12: Average surfclam effort by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

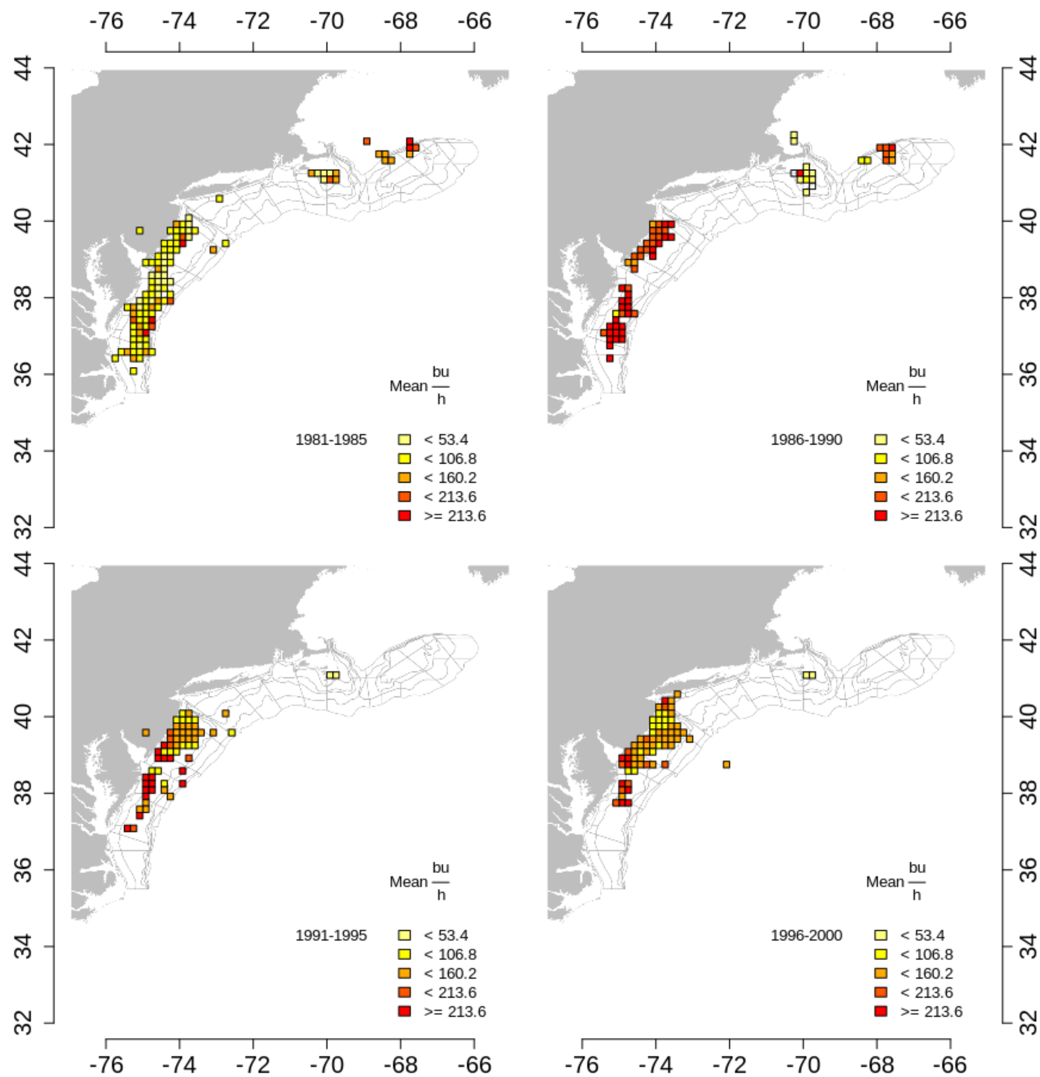



Figure 13: Average surfclam LPUE (bu. $h^{-1}$) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

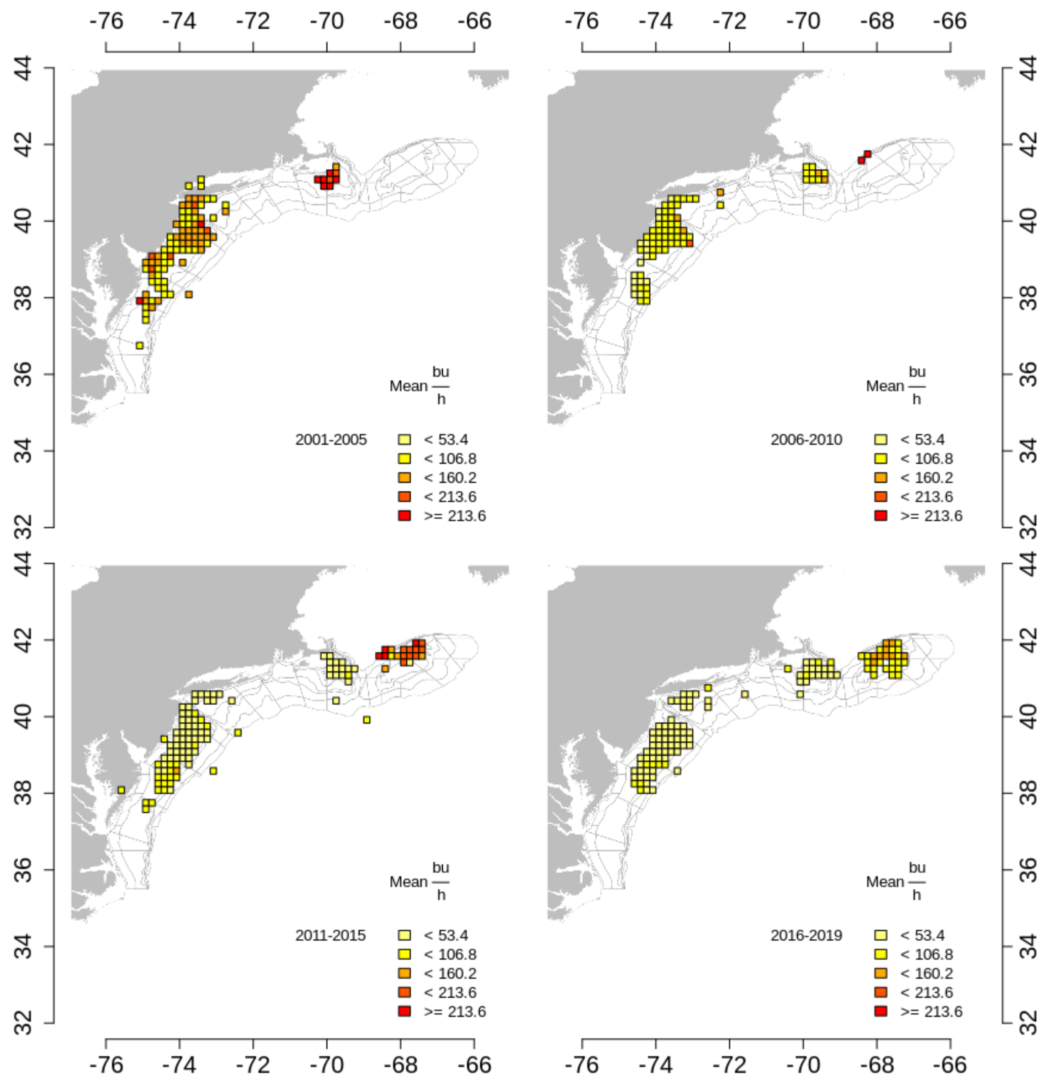



Figure 14: Average surfclam LPUE (bu. $h^{-1}$) by ten-minute squares over time. Only squares where more the 10 kilo bushels were caught are shown.

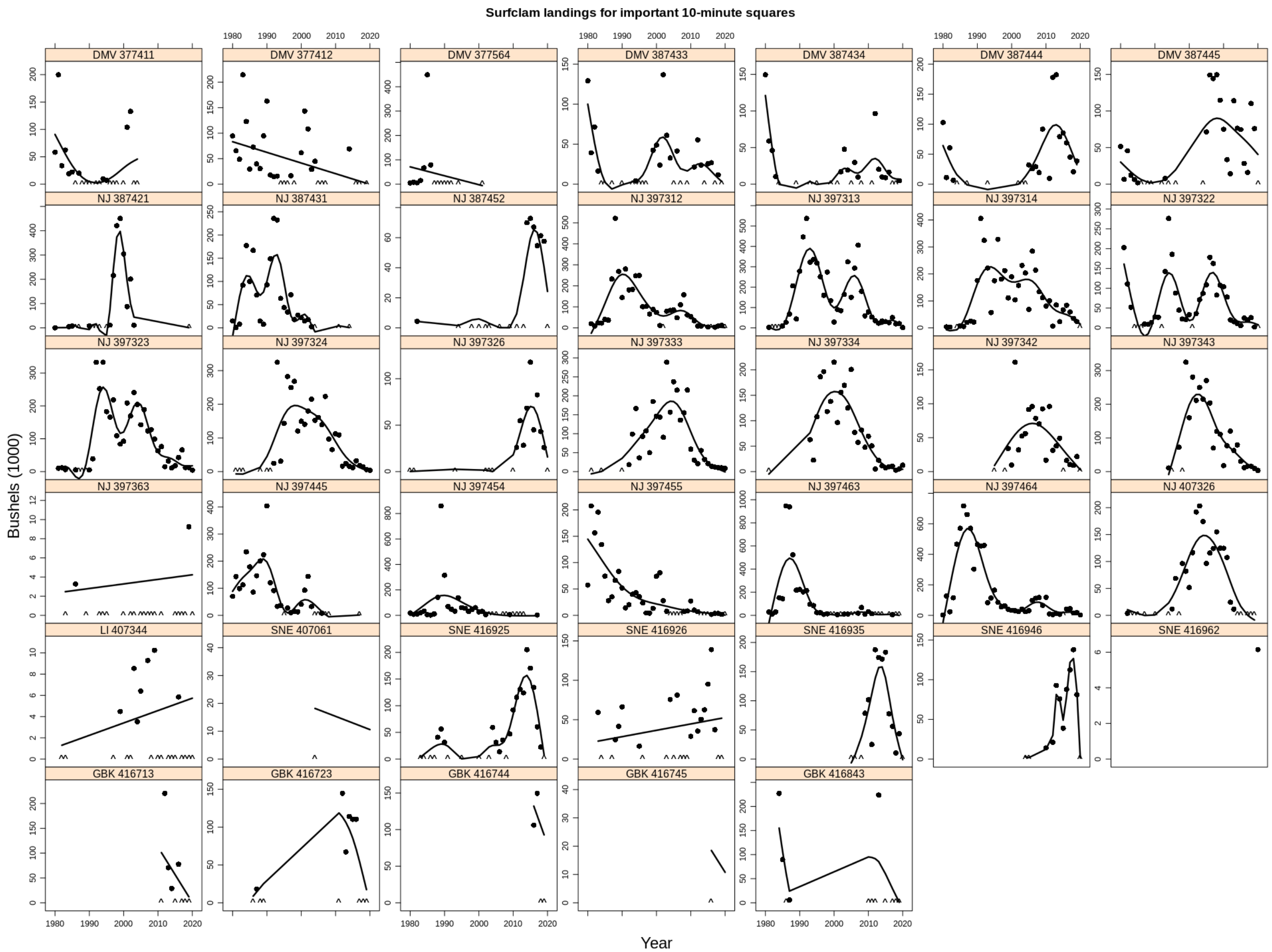



Figure 15: Annual surfclam landings in "important" ten minute squares (TNMS) during 1980-2019 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2019). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

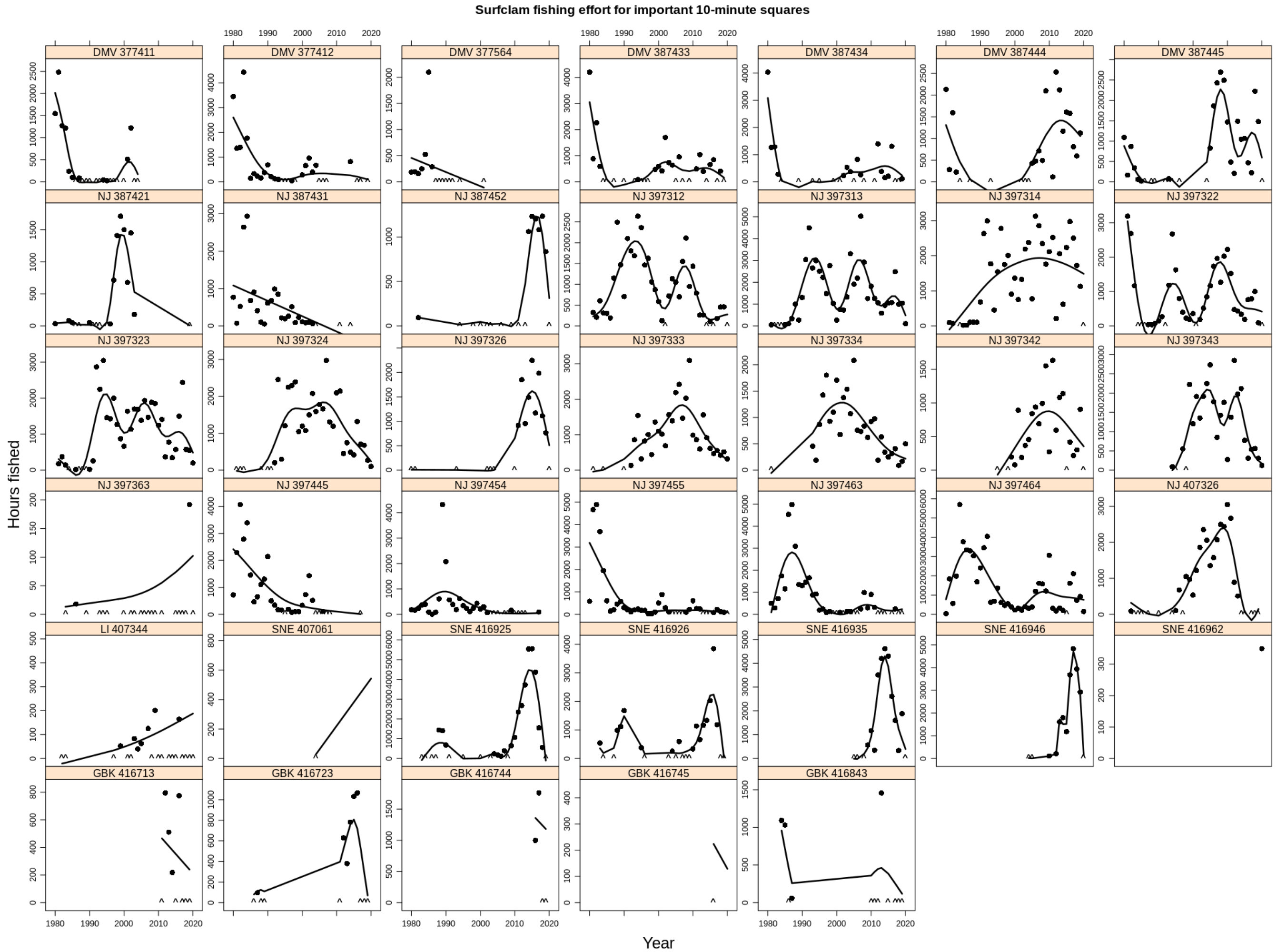



Figure 16: Annual surfclam effort (hours $y^{-1}$) in "important" ten minute squares (TNMS) during 1980-2019 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2019). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

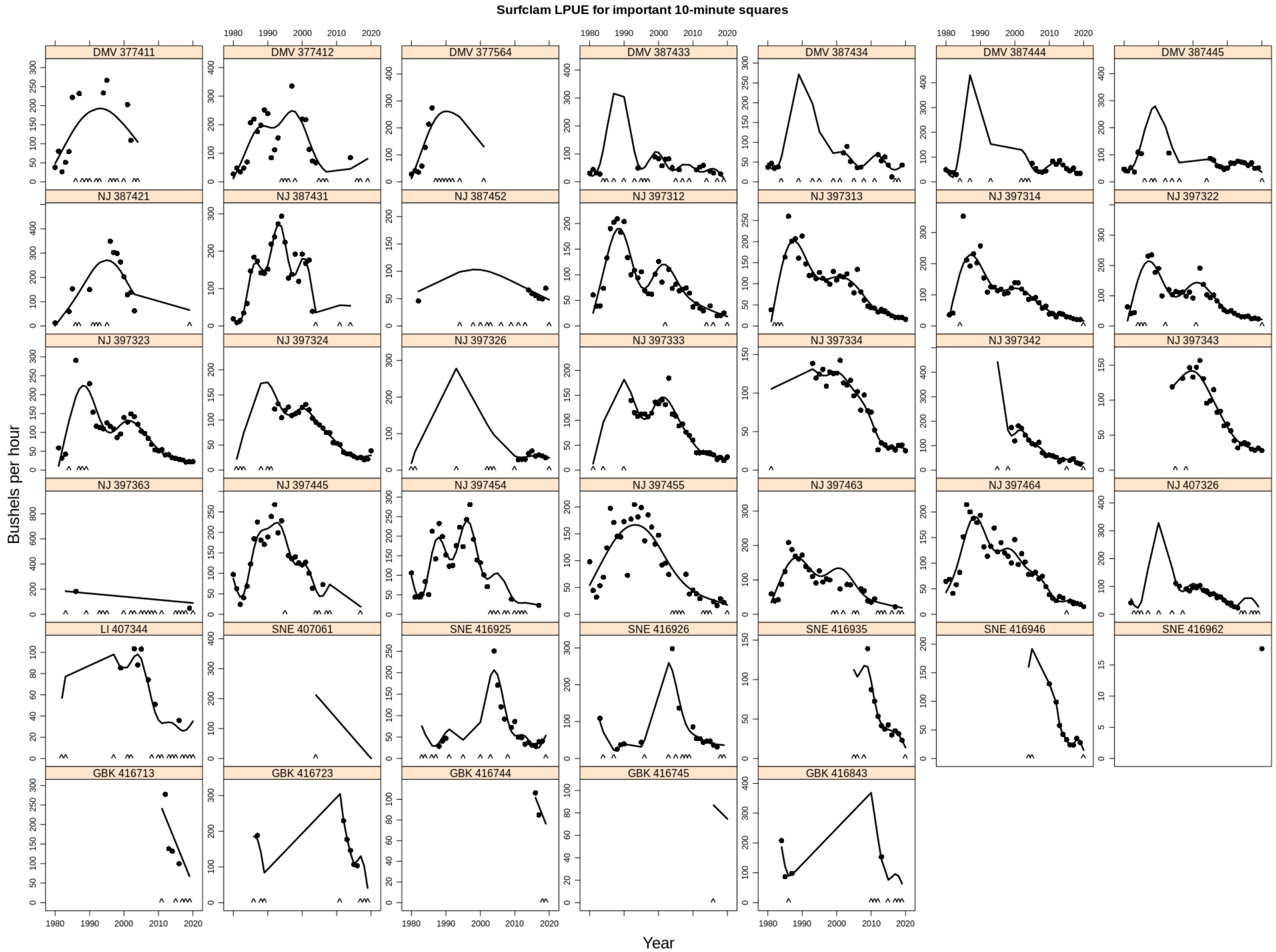



Figure 17: Annual surfclam LPUE (bu $h^{-1}$) in "important" ten minute squares (TNMS) during 1980-2019 based on logbook data. Important means that a square ranked in the top 10 TNMS for total landings during any five-year period (1980-1984, 1985-1989, ..., 2000-2004, 2005-2009, 2010-2019). To protect the privacy of individual firms, data are not plotted if the number of vessels is less than 3. Instead, a "$\wedge$" is shown on the x-axis to indicate where data are missing. The solid dark line is a spline intended to show trends. The spline was fit too all available data, including data not plotted.

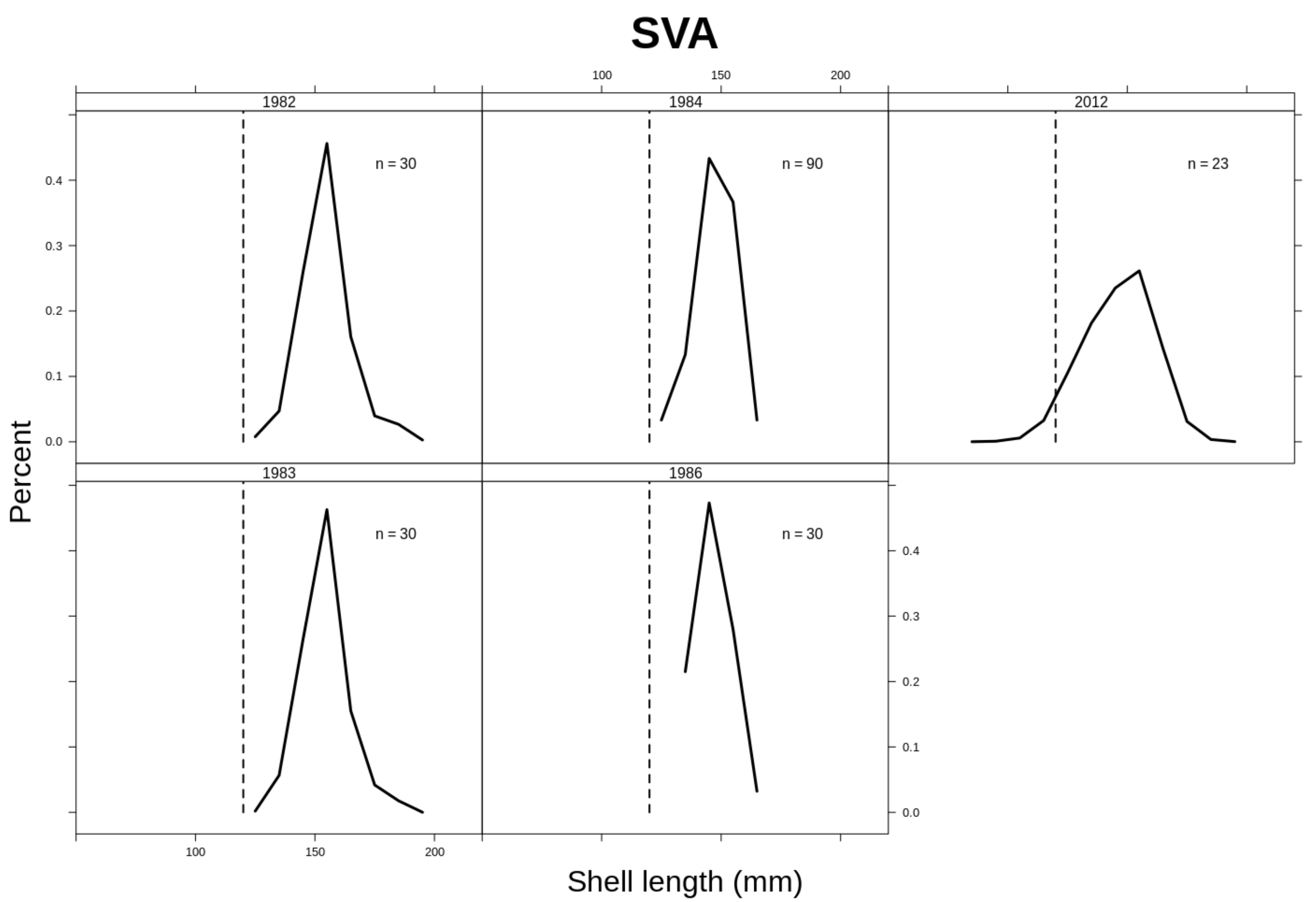



Figure 18: Length compositions for Atlantic surfclam from port samples of landings from the SVA region. Sample sizes are the number of clams measured in each year.

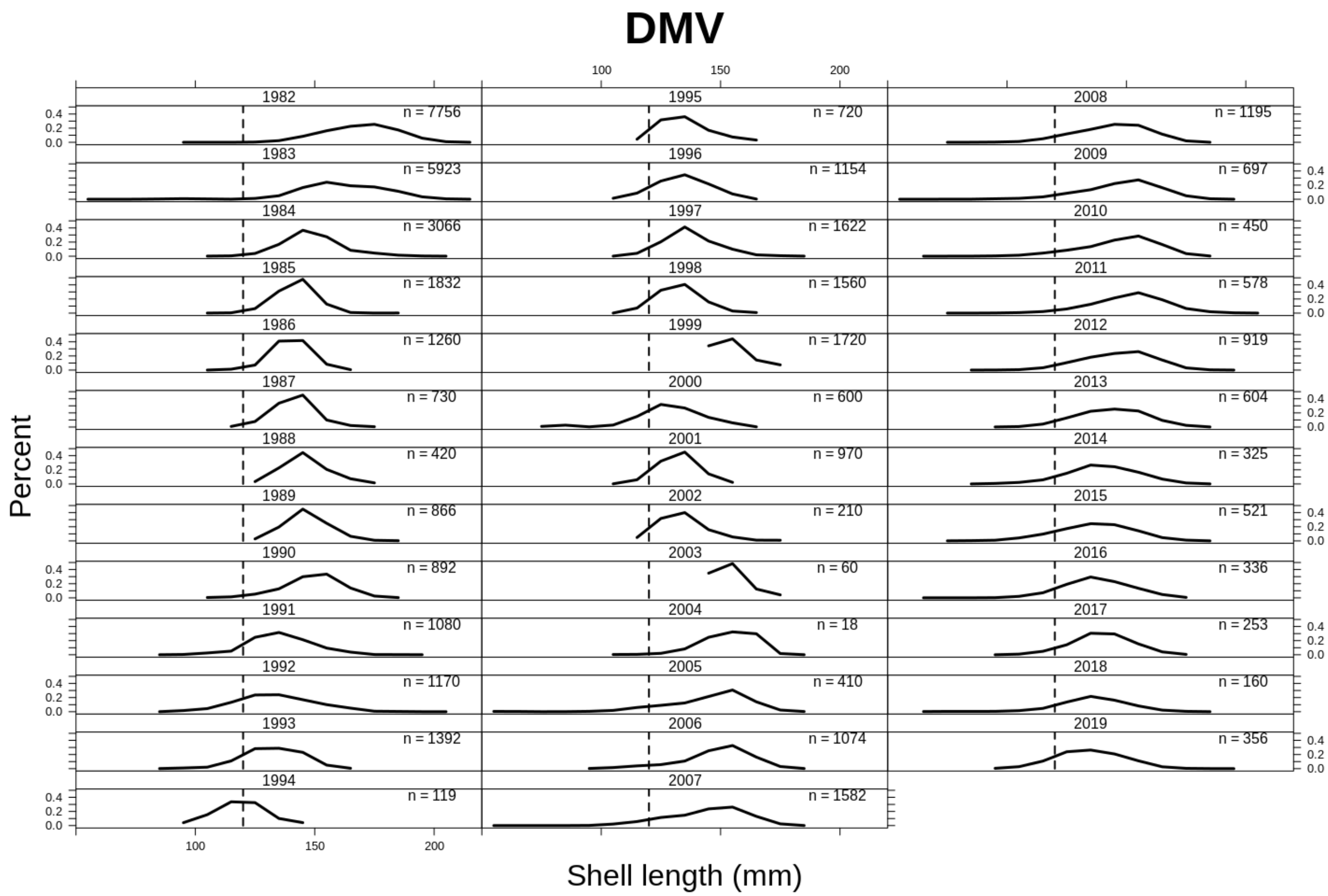



Figure 19: Length compositions for Atlantic surfclam from port samples of landings from the DMV region. Sample sizes are the number of clams measured in each year.

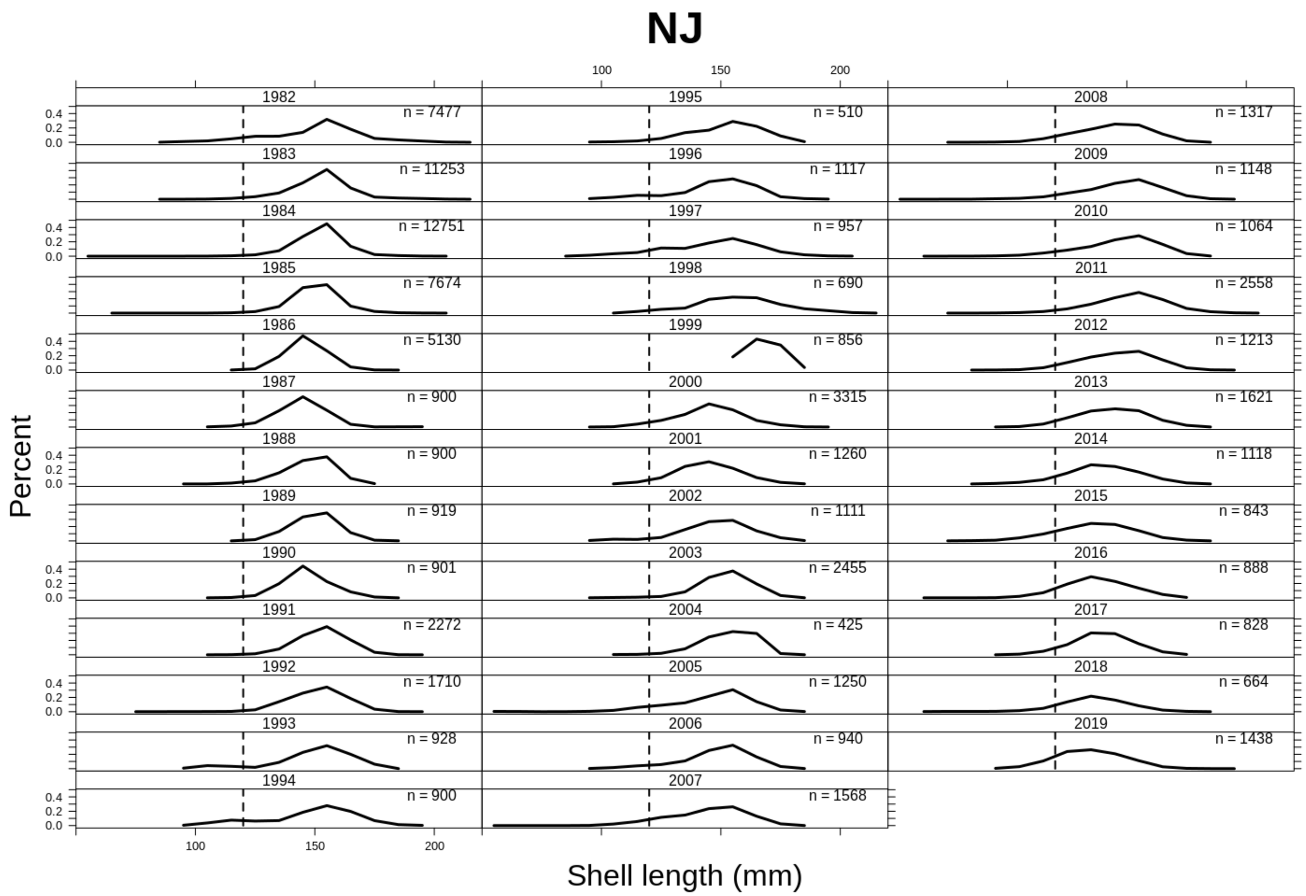



Figure 20: Length compositions for Atlantic surfclam from port samples of landings from the NJ region. Sample sizes are the number of clams measured in each year.

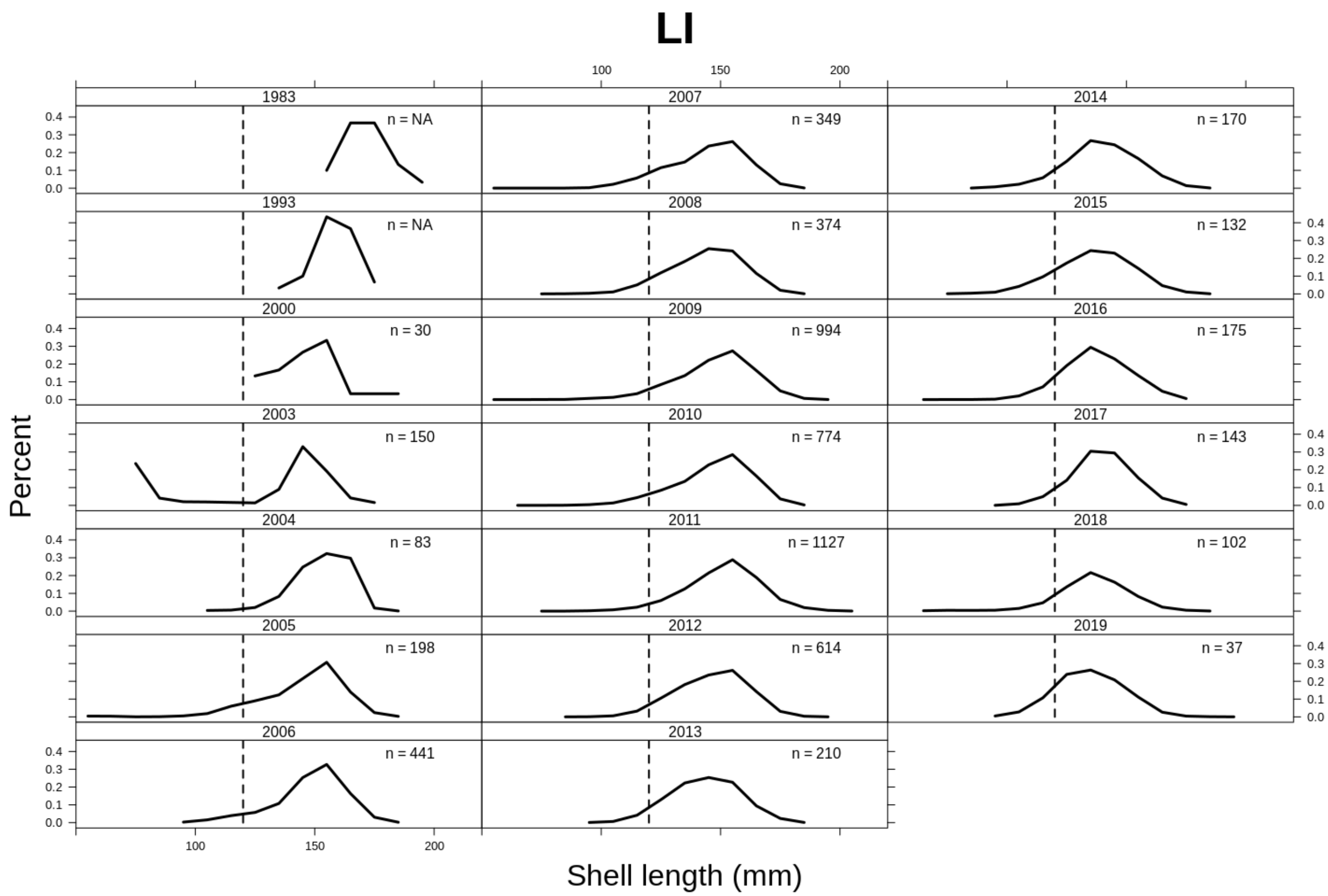



Figure 21: Length compositions for Atlantic surfclam from port samples of landings from the LI region. Sample sizes are the number of clams measured in each year.

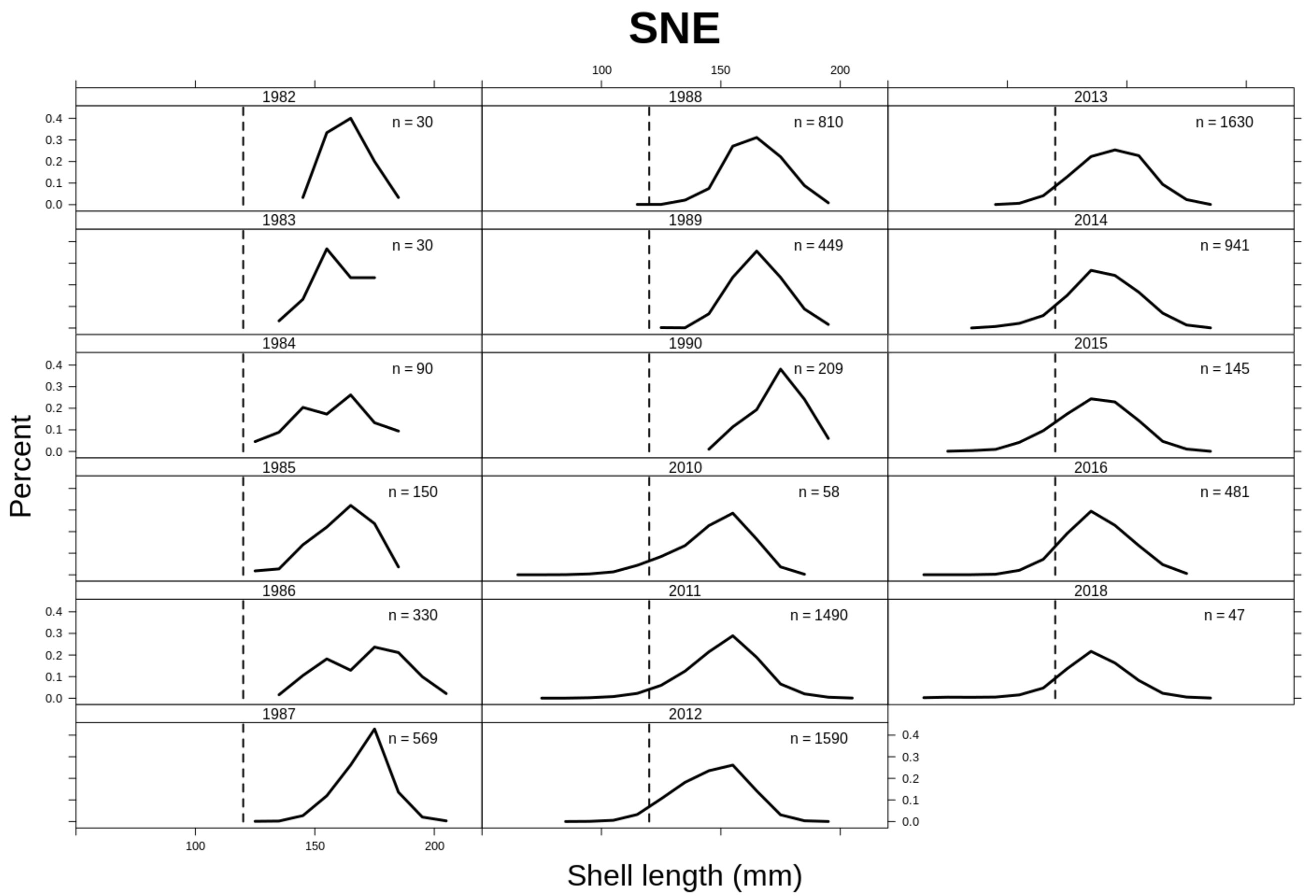



Figure 22: Length compositions for Atlantic surfclam from port samples of landings from the SNE region. Sample sizes are the number of clams measured in each year.

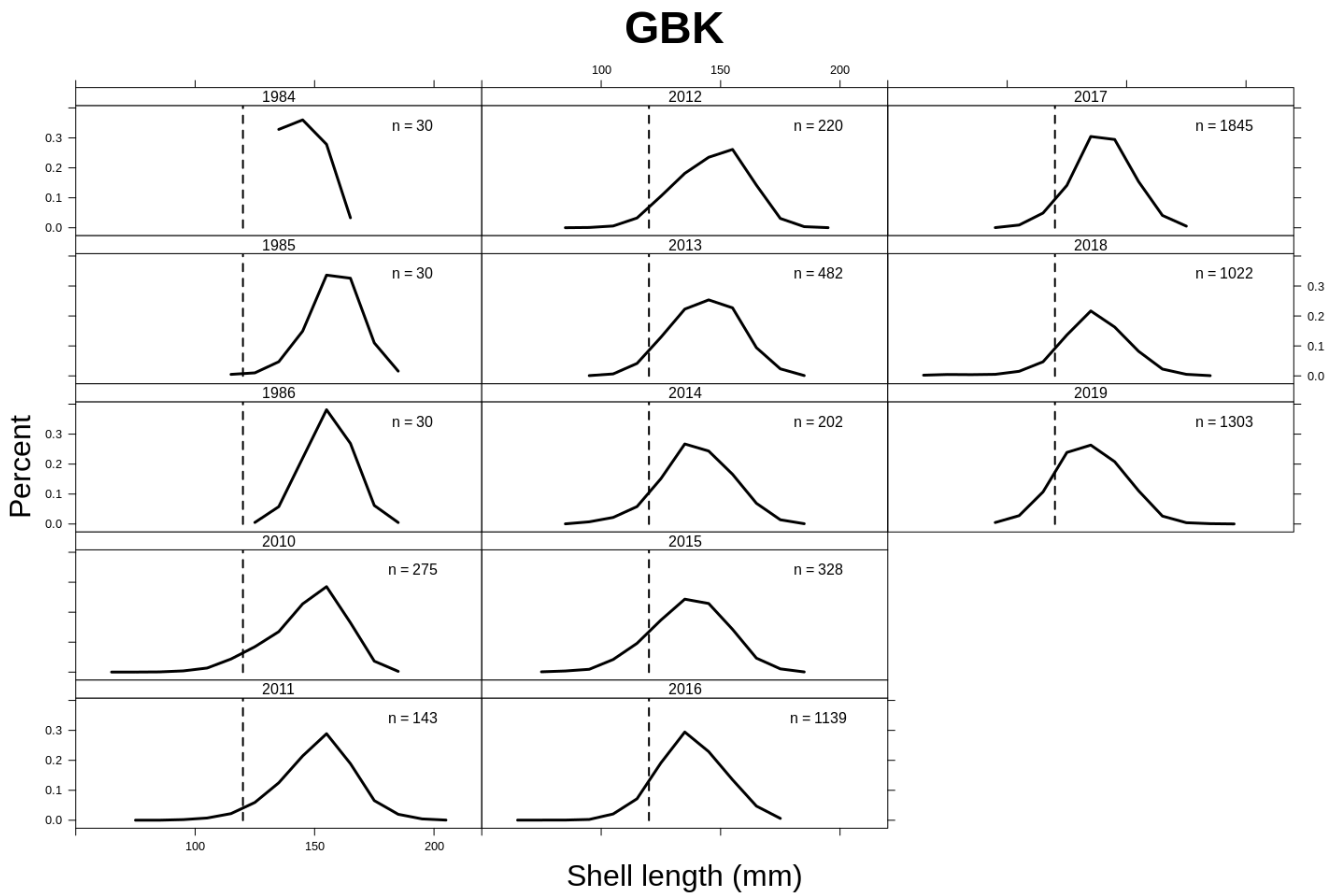



Figure 23: Length compositions for Atlantic surfclam from port samples of landings from the GBK region. Sample sizes are the number of clams measured in each year.

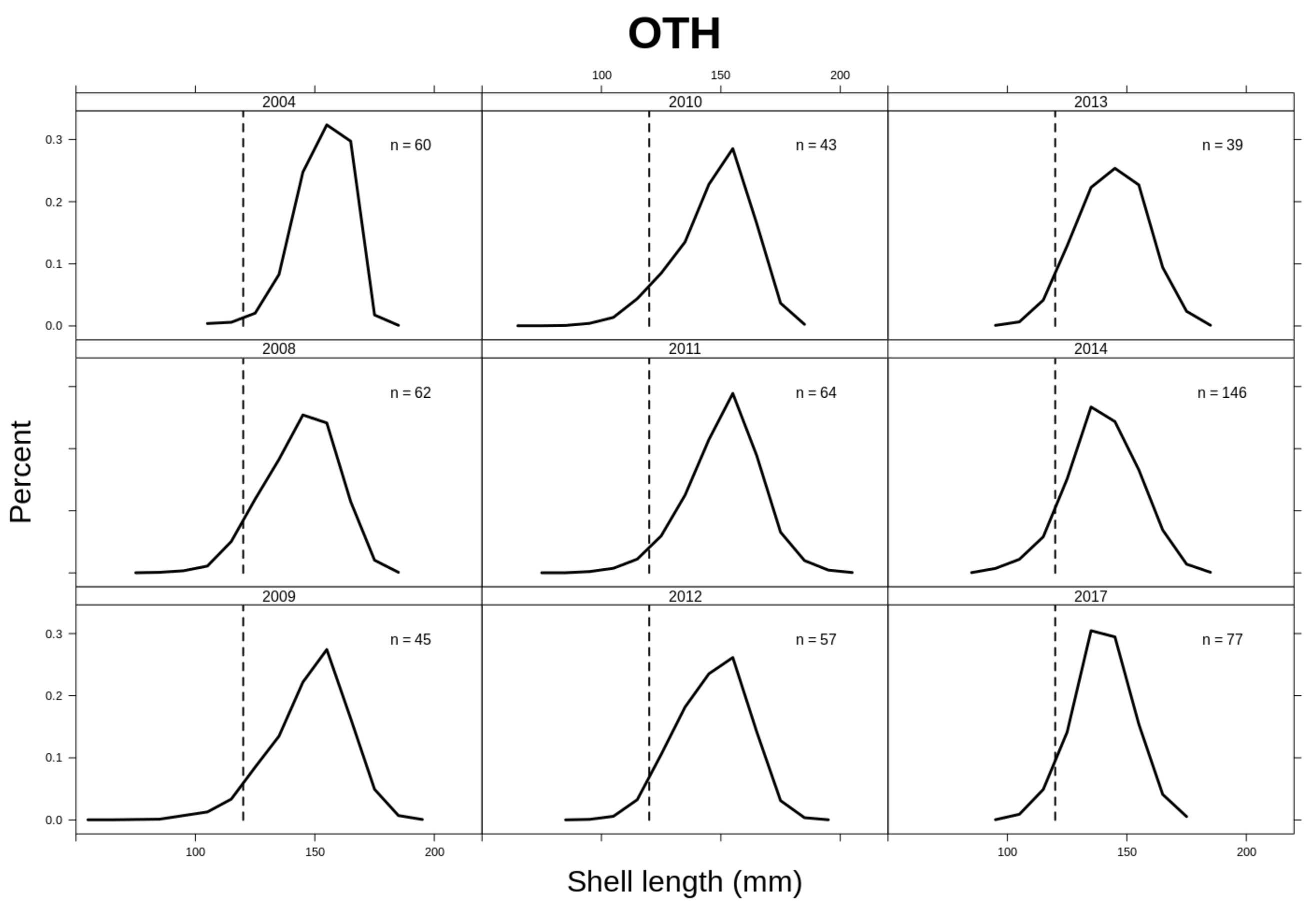



Figure 24: Length compositions for Atlantic surfclam for which no area was recorded (OTH). Sample sizes are the number of clams measured in each year.

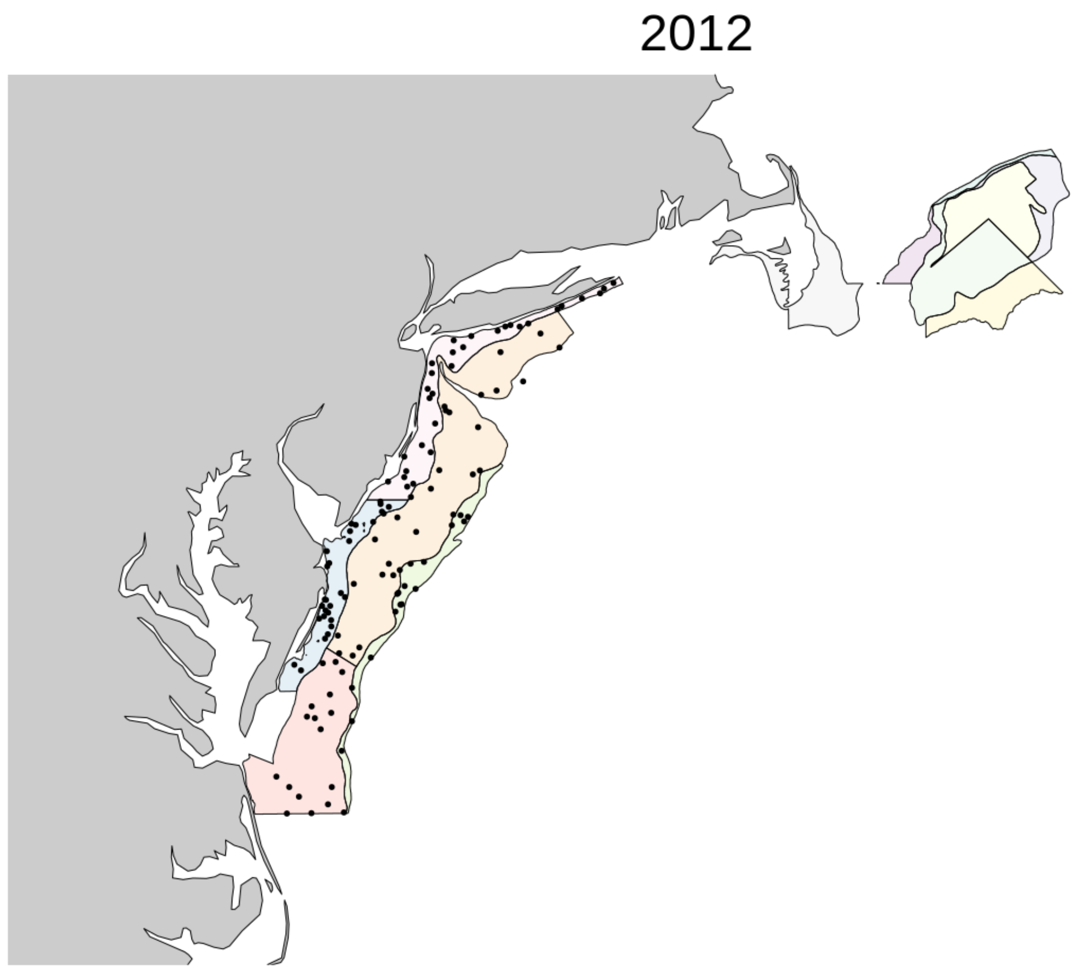



Figure 25: Station locations from the 2012 survey

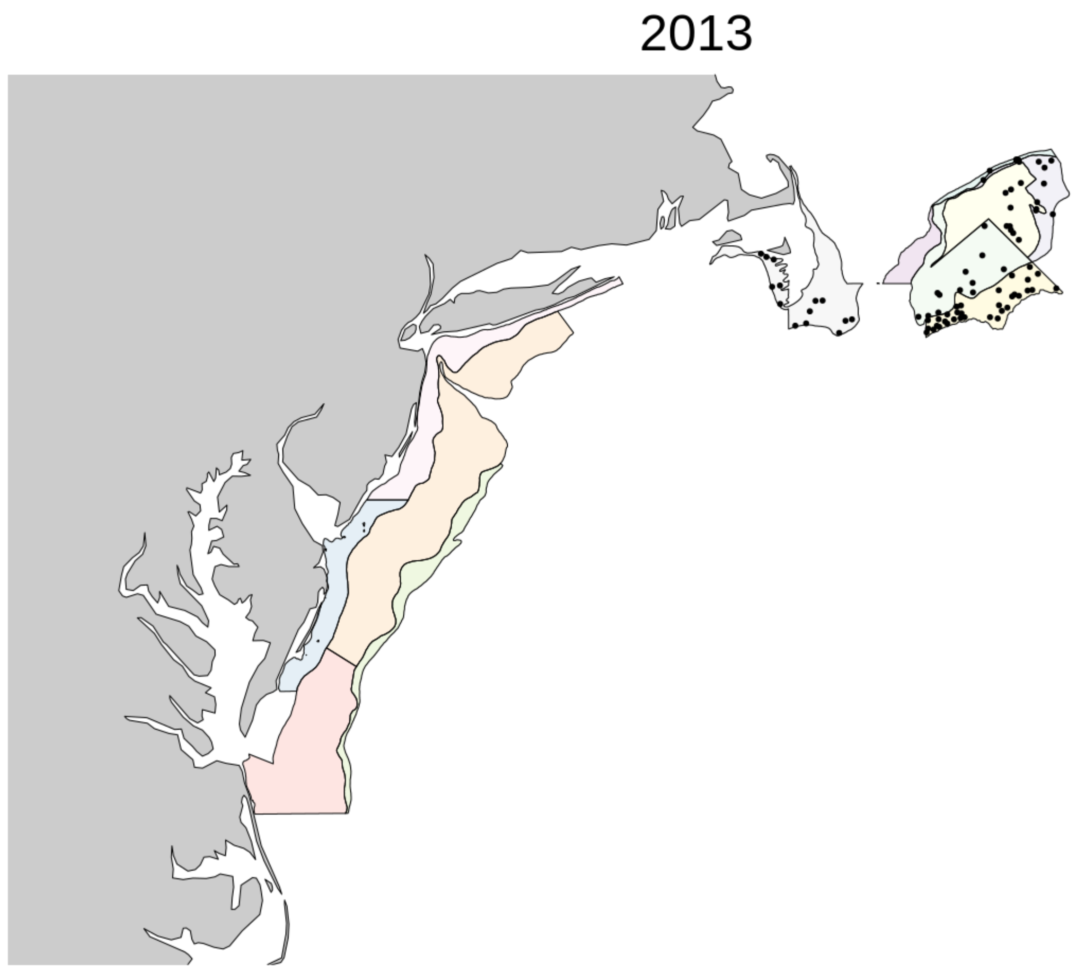



Figure 26: Station locations from the 2013 survey

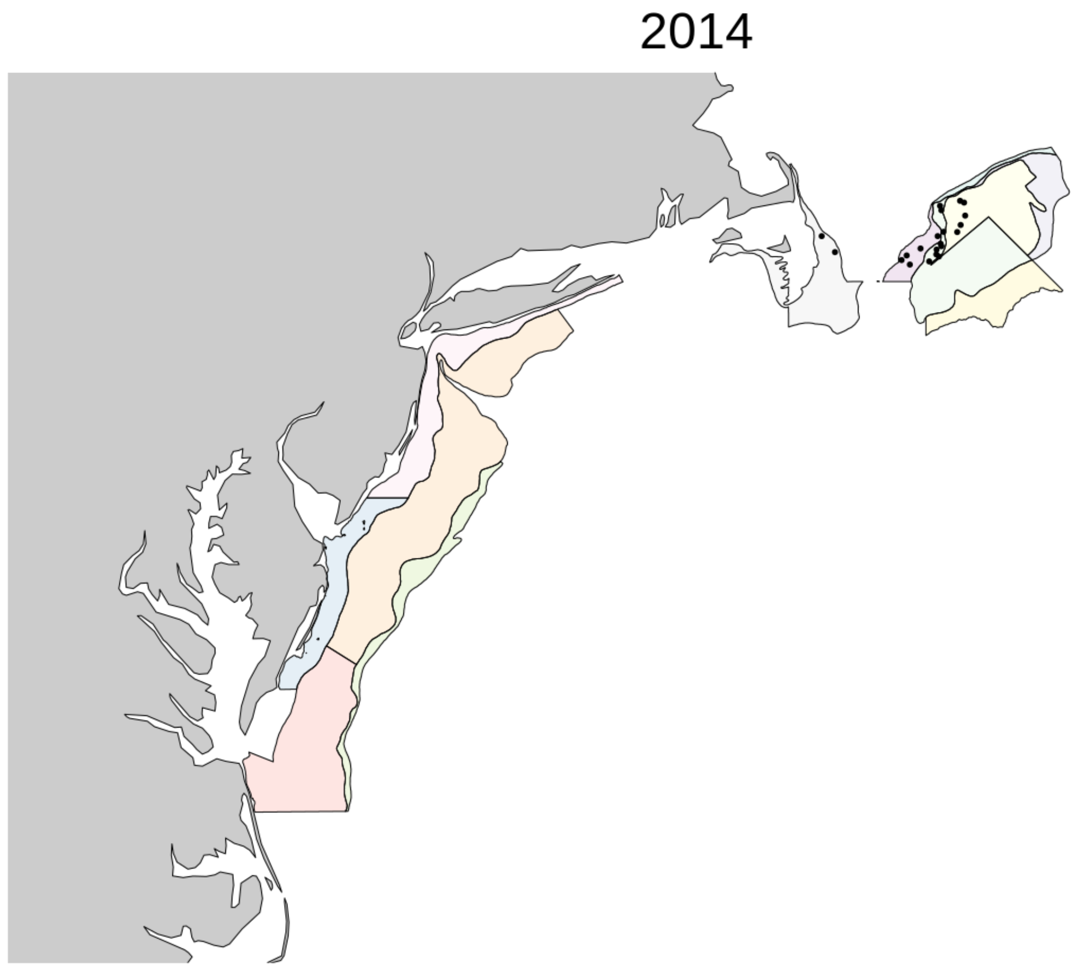



Figure 27: Station locations from the 2014 survey

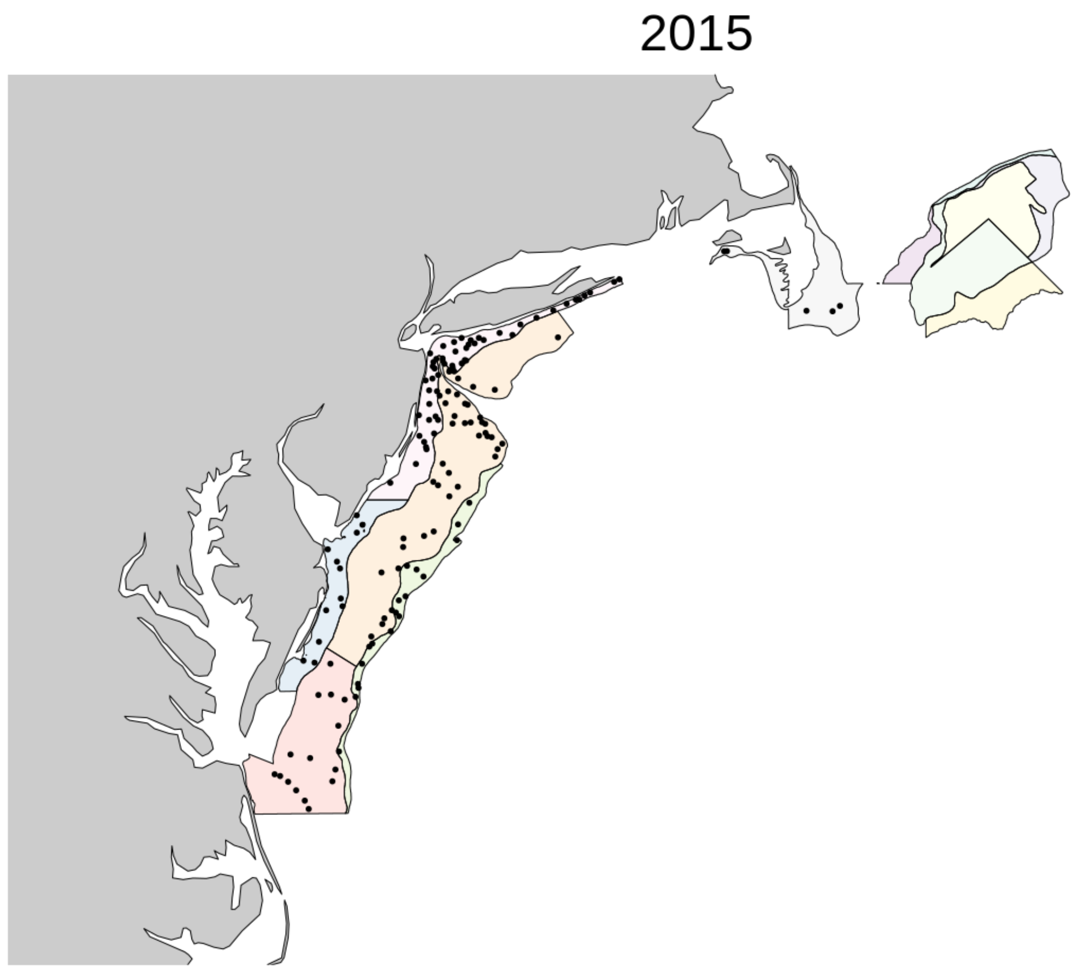



Figure 28: Station locations from the 2015 survey

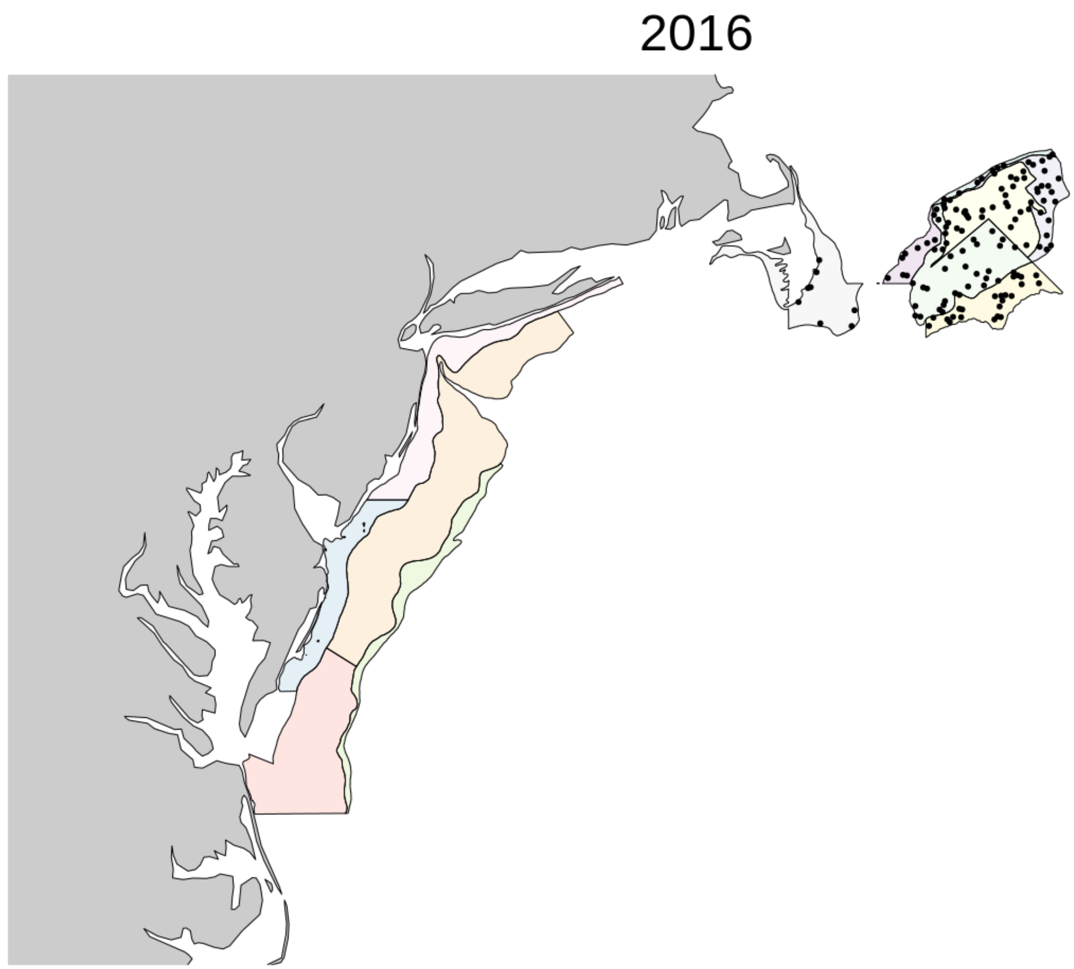



Figure 29: Station locations from the 2016 survey

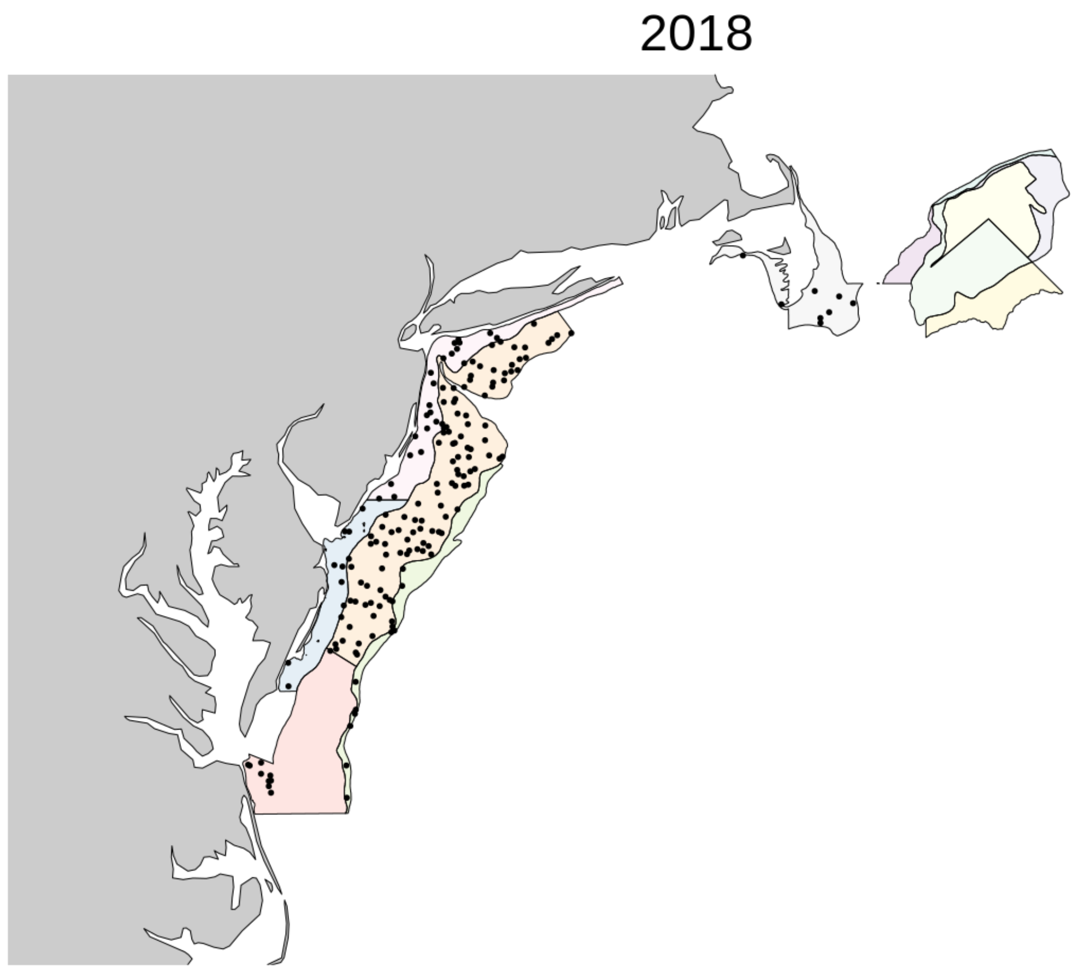



Figure 30: Station locations from the 2018 survey

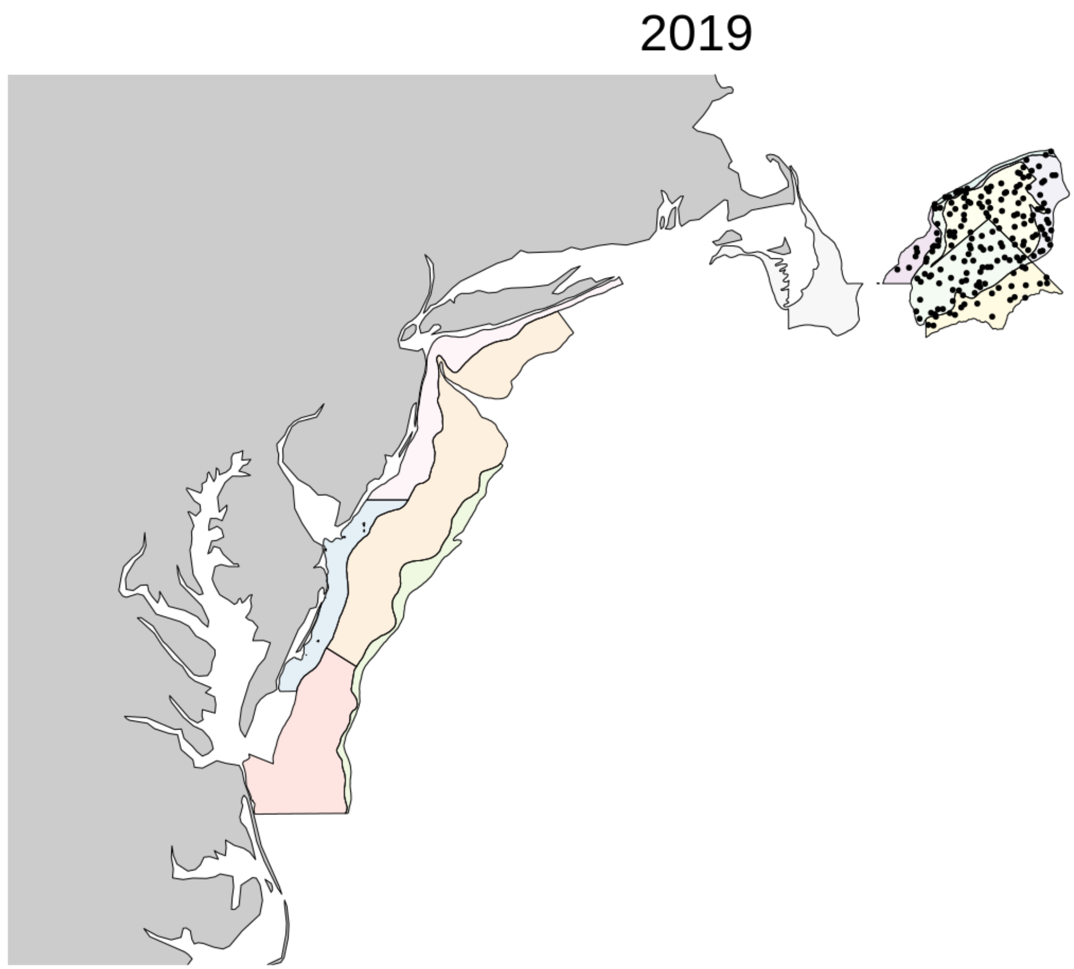



Figure 31: Station locations from the 2018 survey

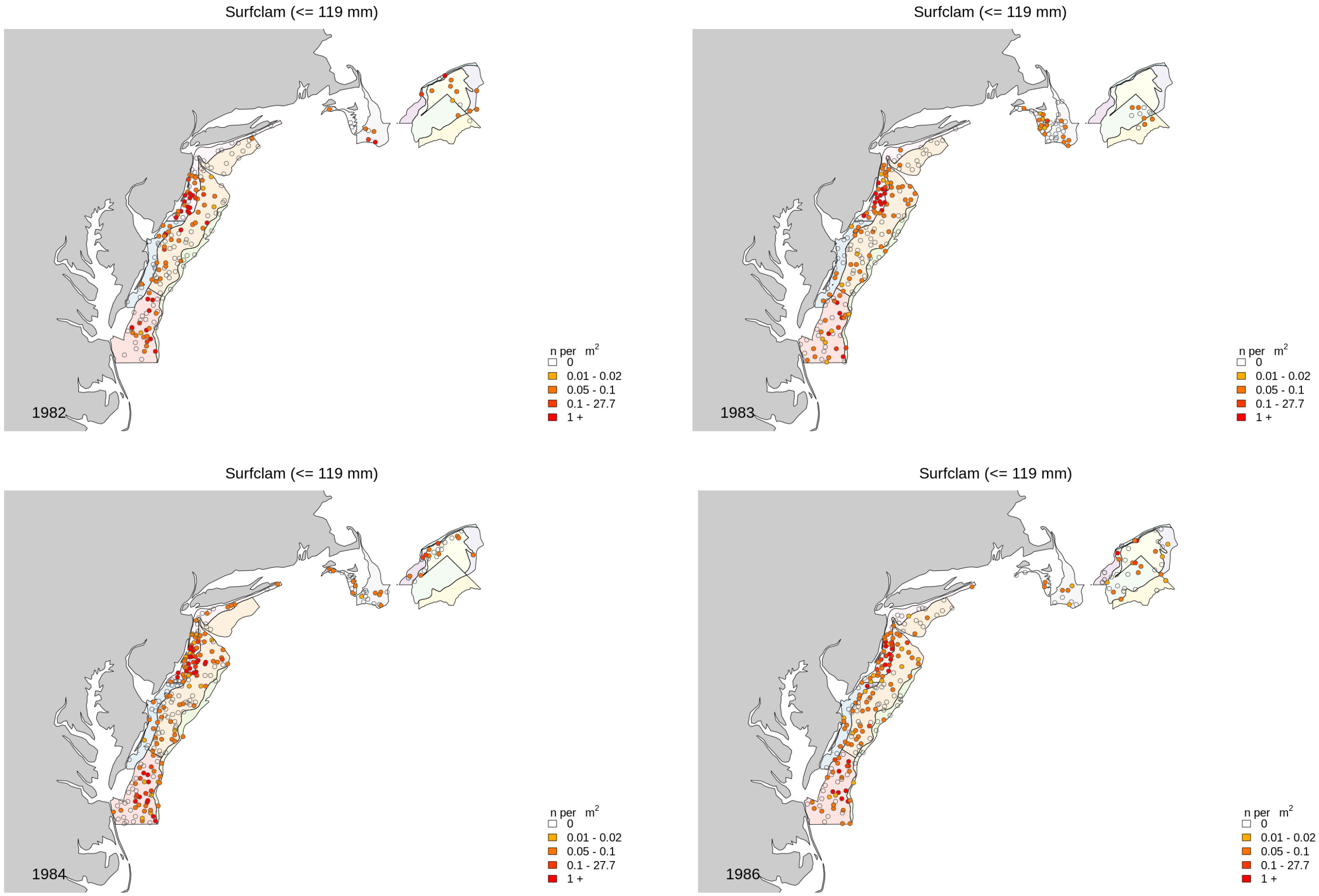
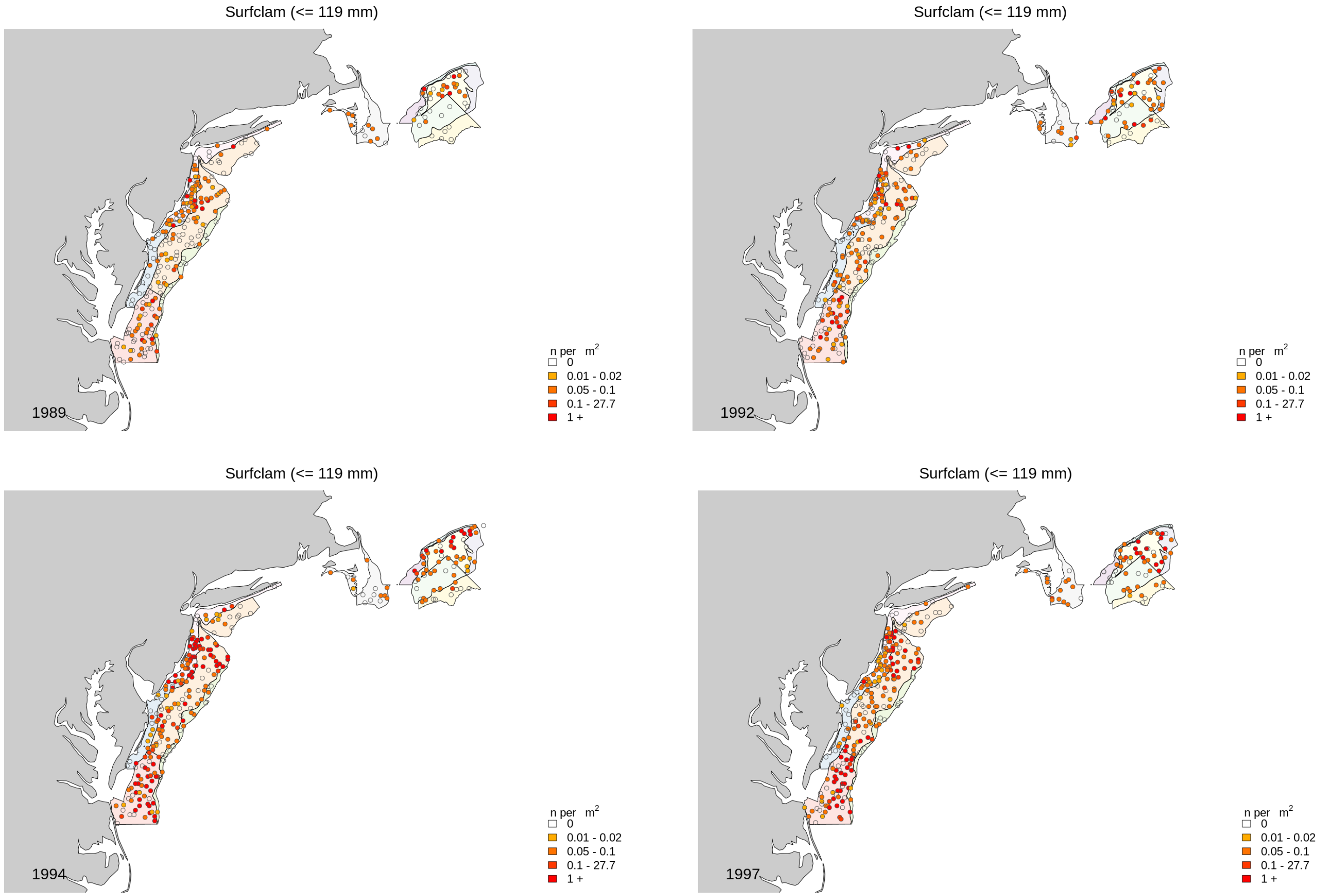



Figure 32: Survey stations where small ($<= 119\ mm$) surfclam were caught, by year.

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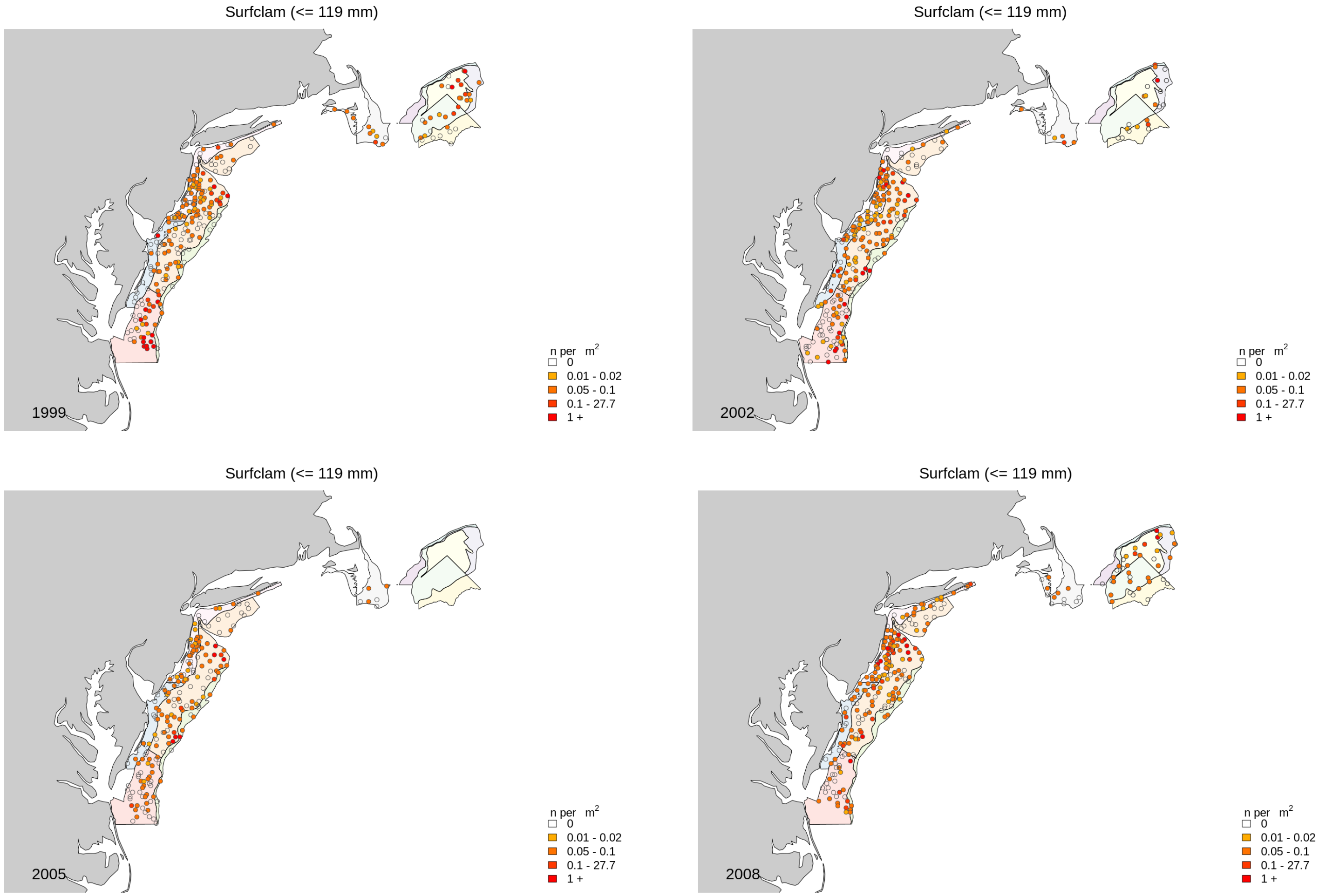


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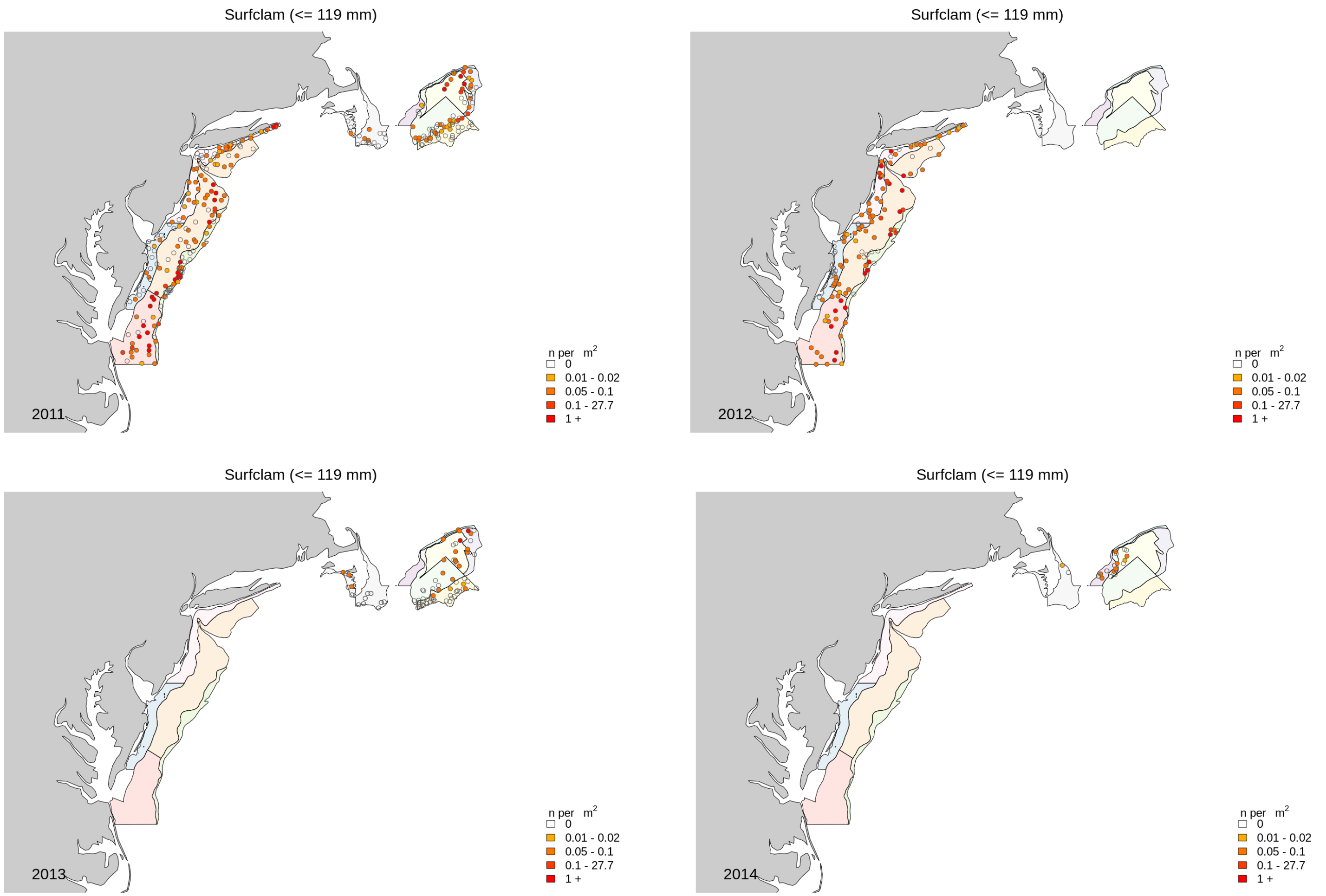


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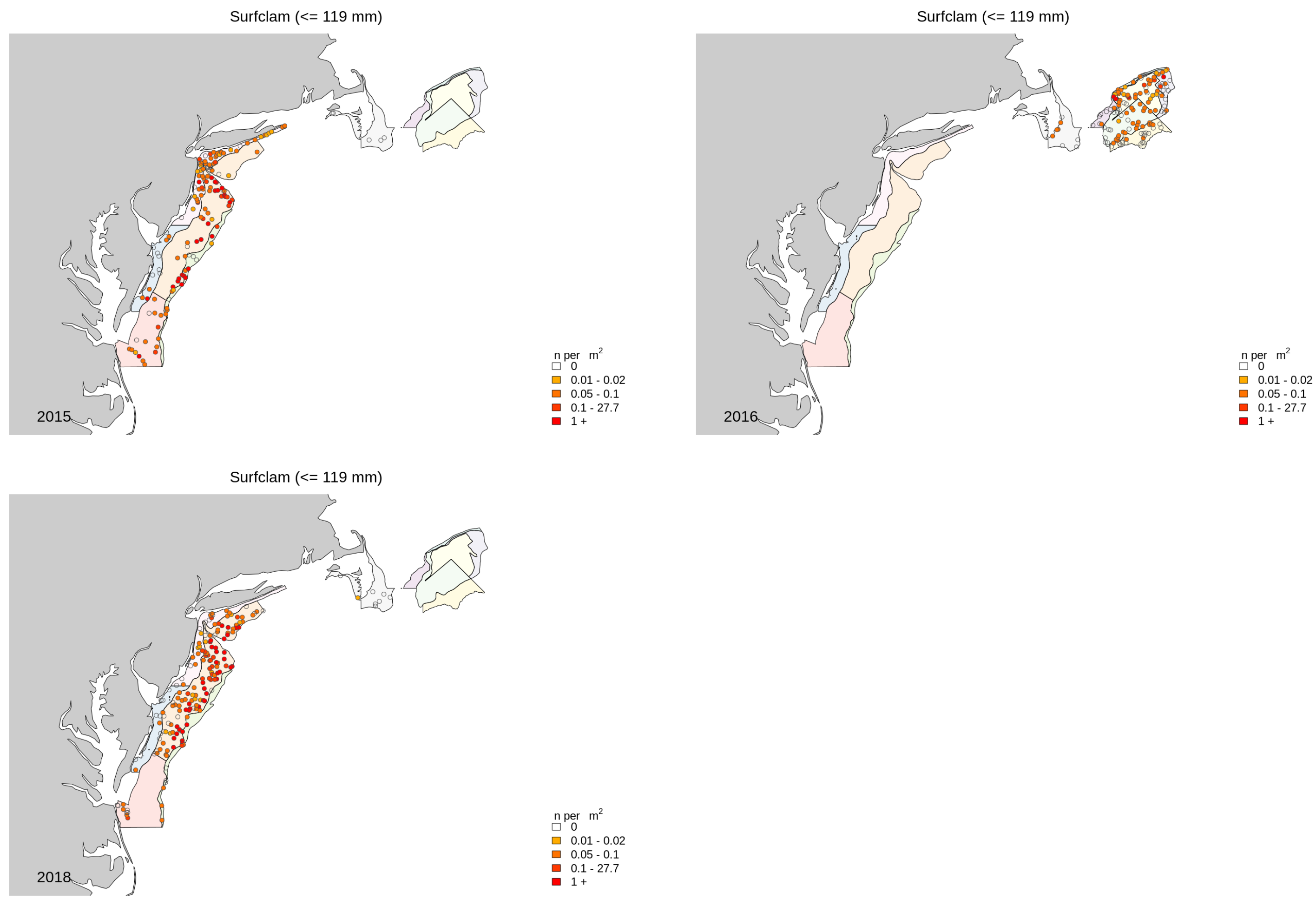


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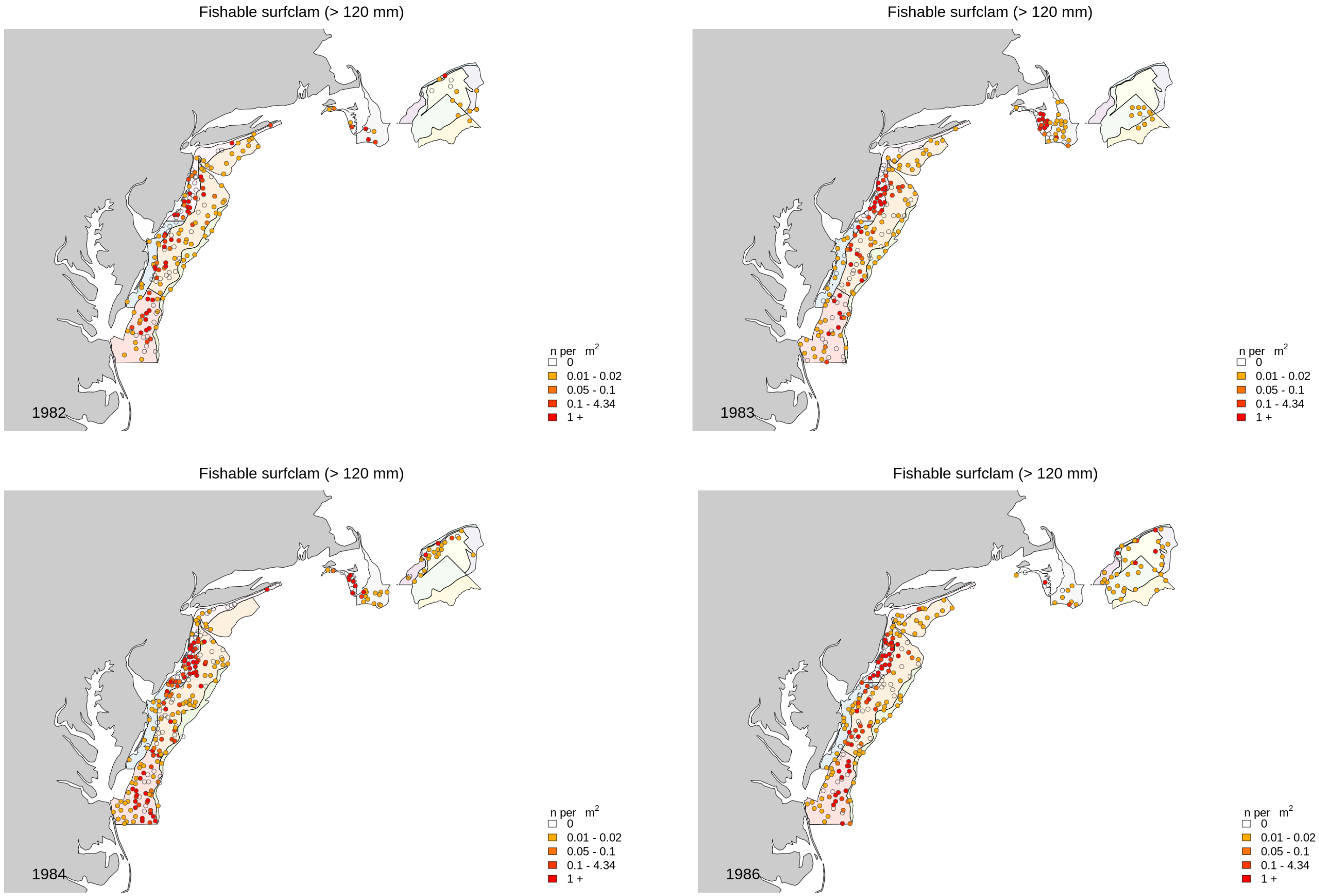



Figure 33: Survey stations where large ($> 120\ mm$) surfclam were caught, by year.

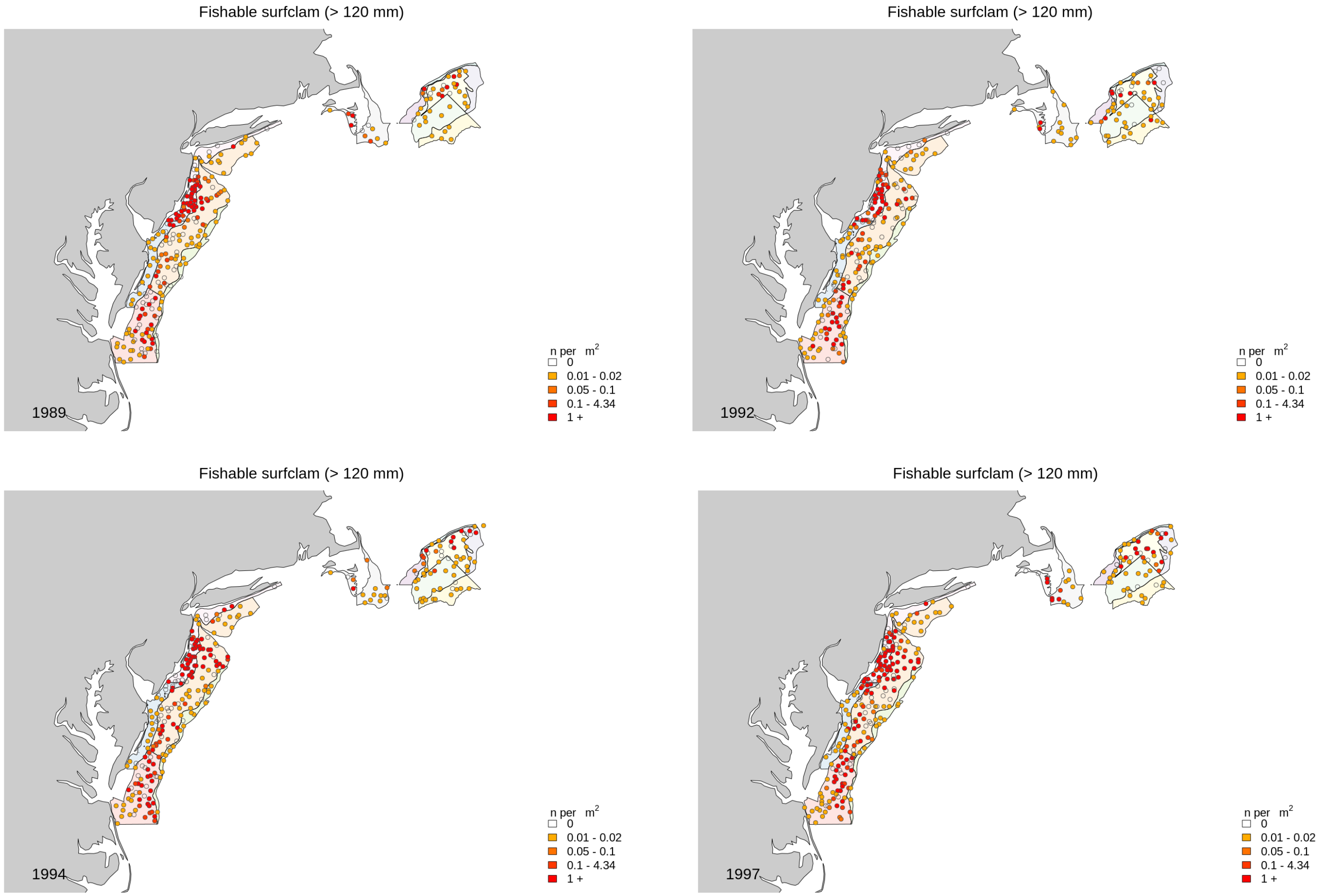
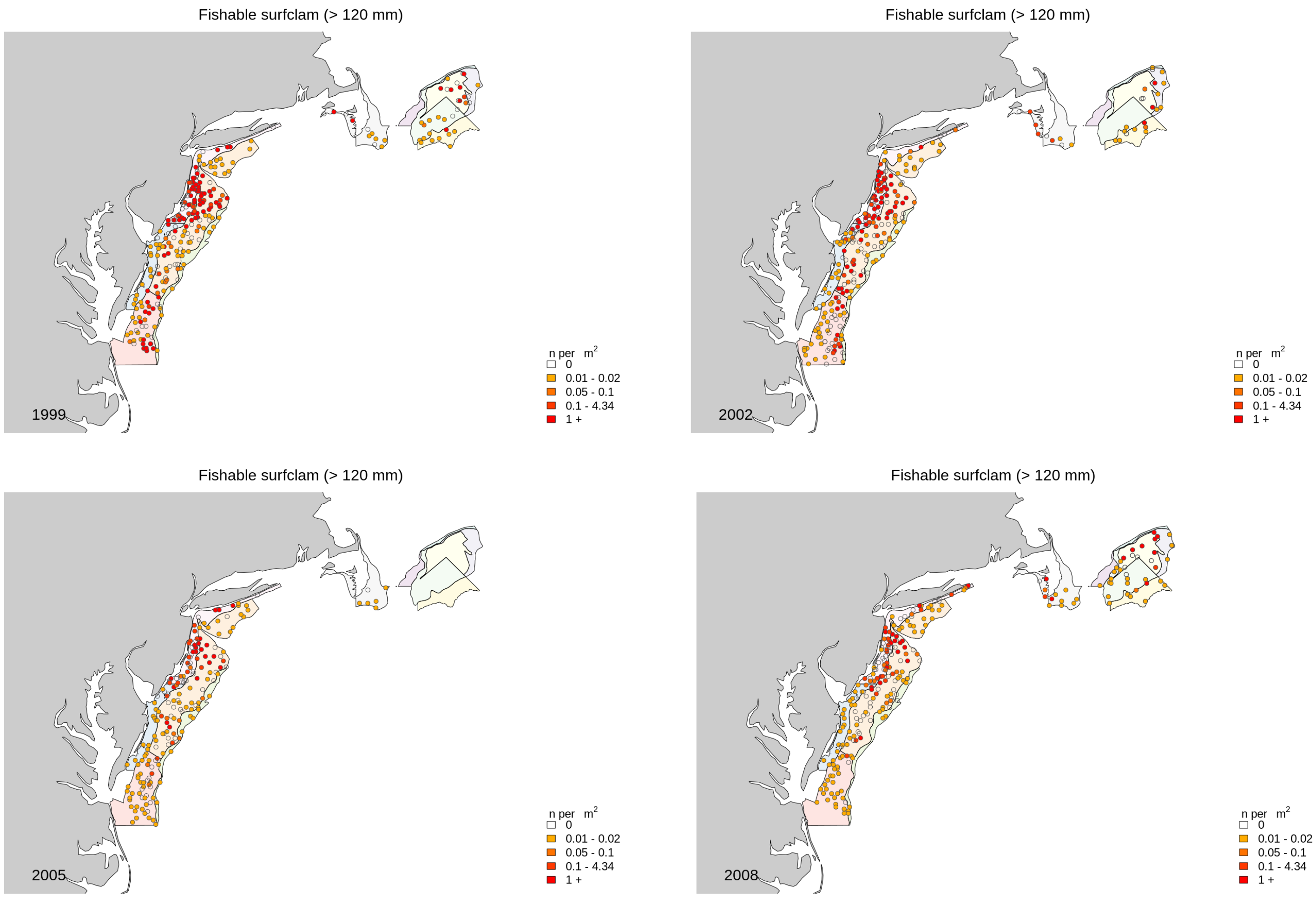



Figure 33 cont.

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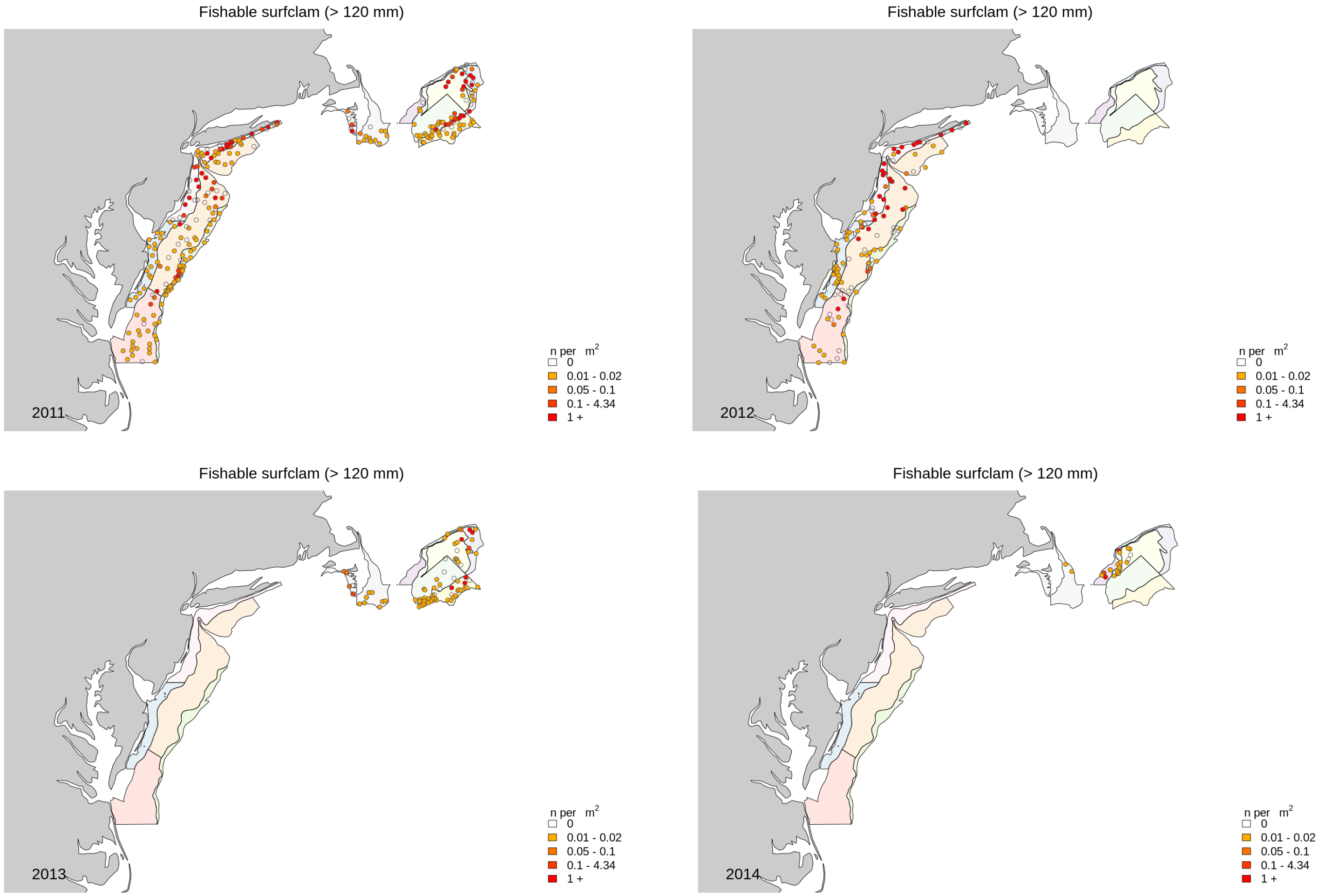
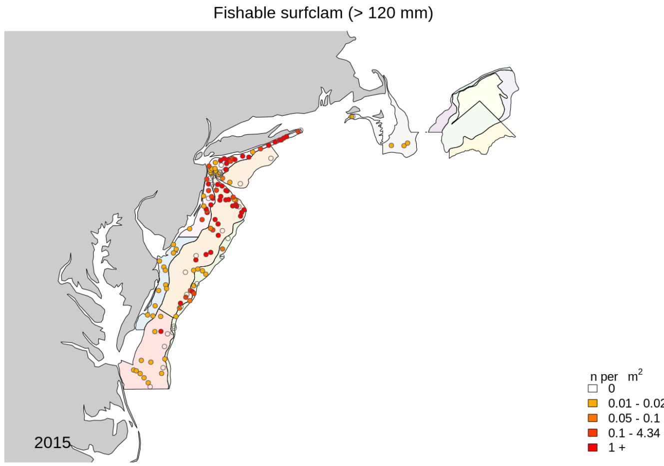
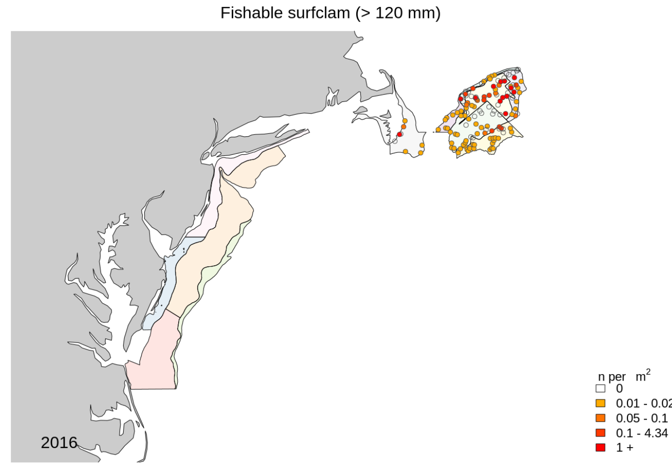



Figure 33 cont.



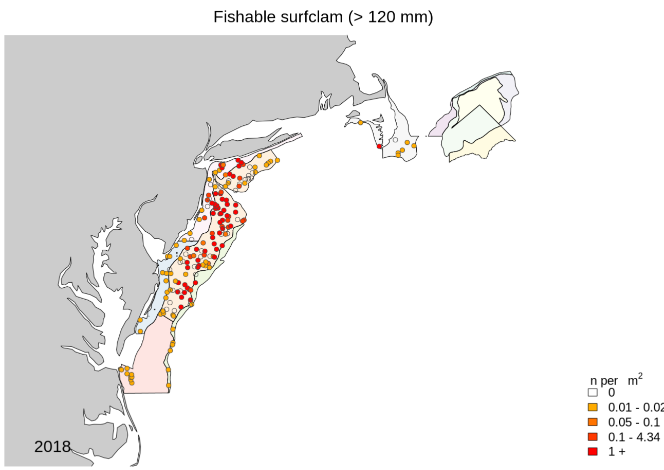




Figure 33 cont.

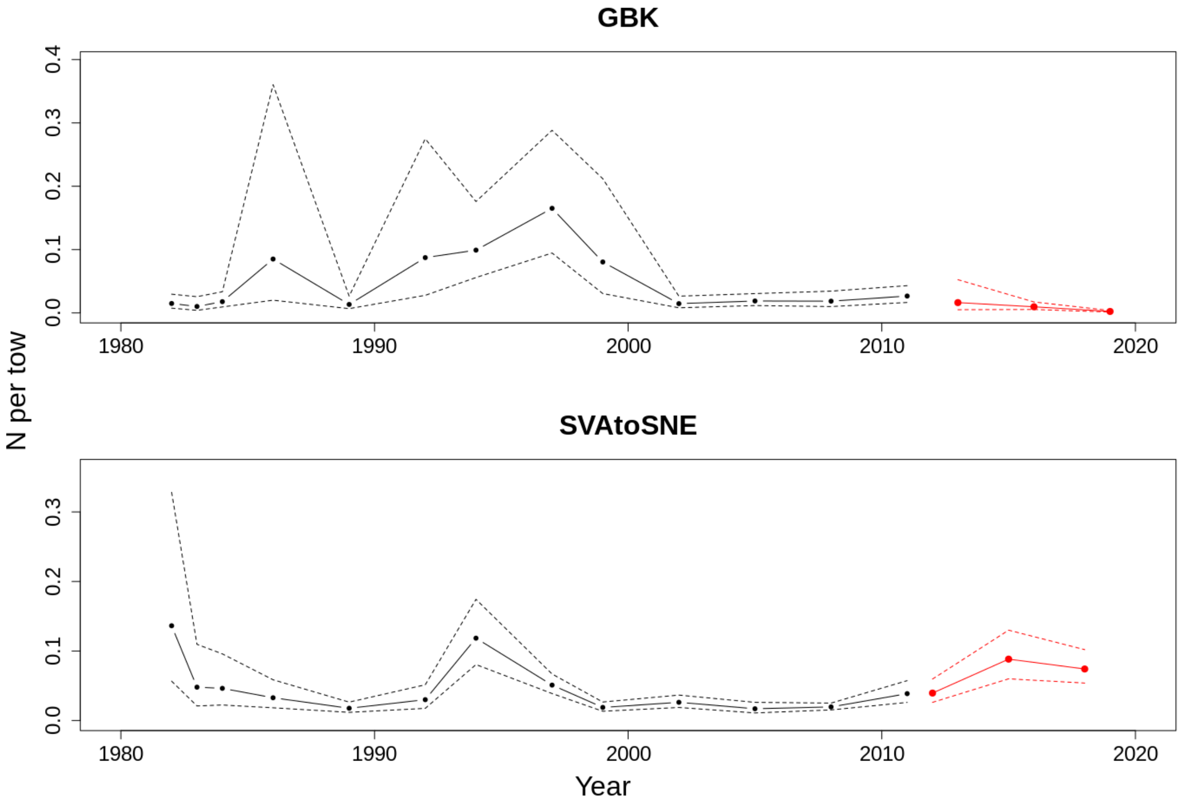



Figure 34: Surfclam 50 – 119 mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate $95\%$ asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

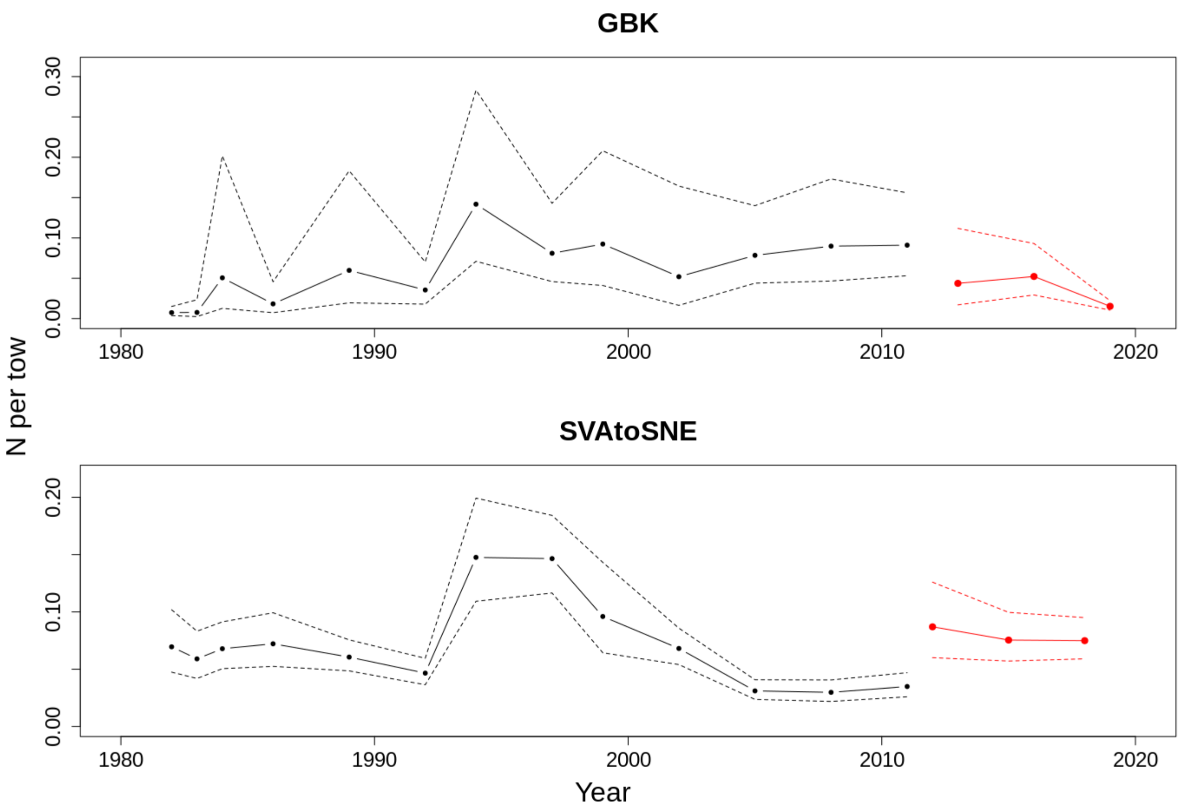



Figure 35: Surfclam $> 119$ mm from NEFSC surveys adjusted for selectivity, but not efficiency, with approximate $95\%$ asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

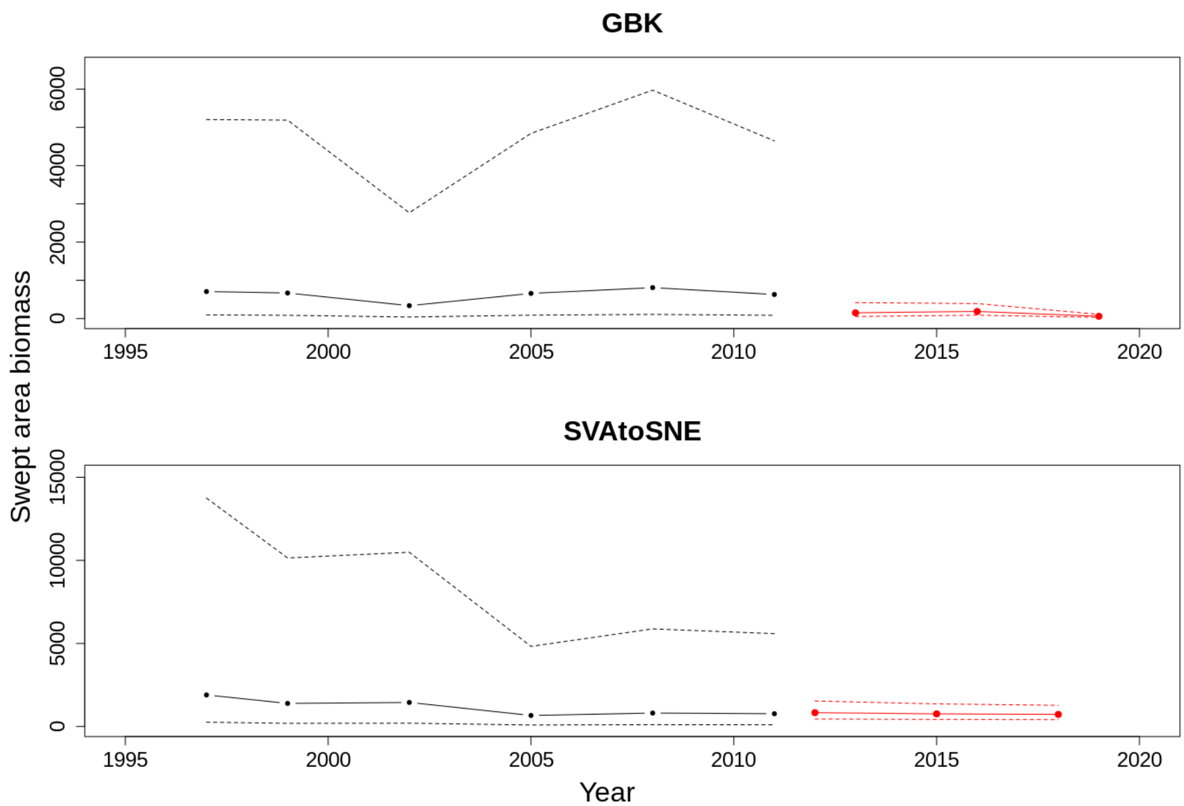



Figure 36: Surfclam swept area biomass from NEFSC surveys adjusted for selectivity and efficiency, with approximate $95\%$ asymmetric confidence intervals, by area. Beginning in 2012, the survey was conducted from a commercial platform using a dredge with higher capture efficiency. Results from the new survey platform are shown as a separate series in red. GBK and SNE were not sampled in 2012 and SVA, DMV, NJ and LI were not sampled in 2013 or 2014.

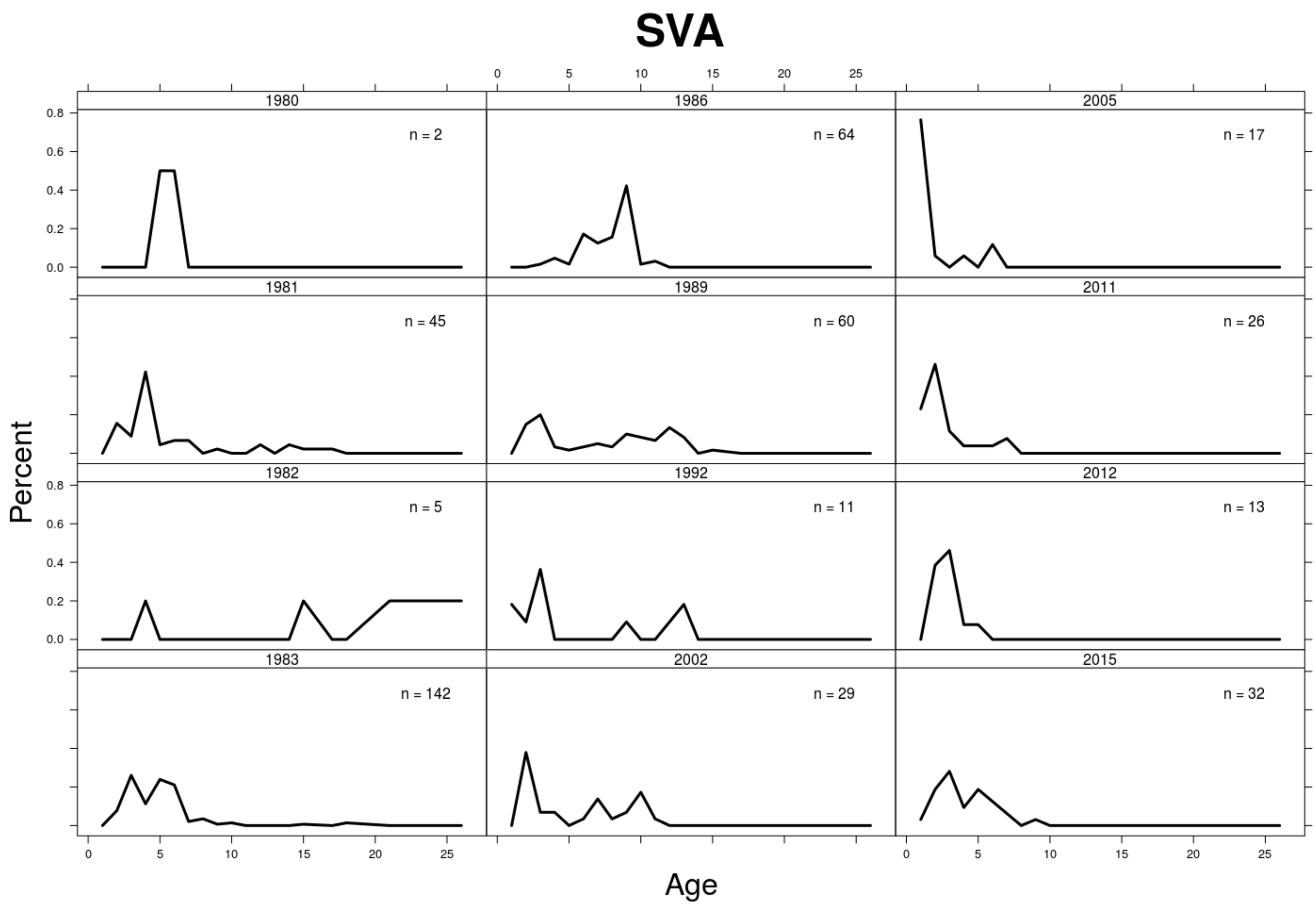



Figure 37: Age composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

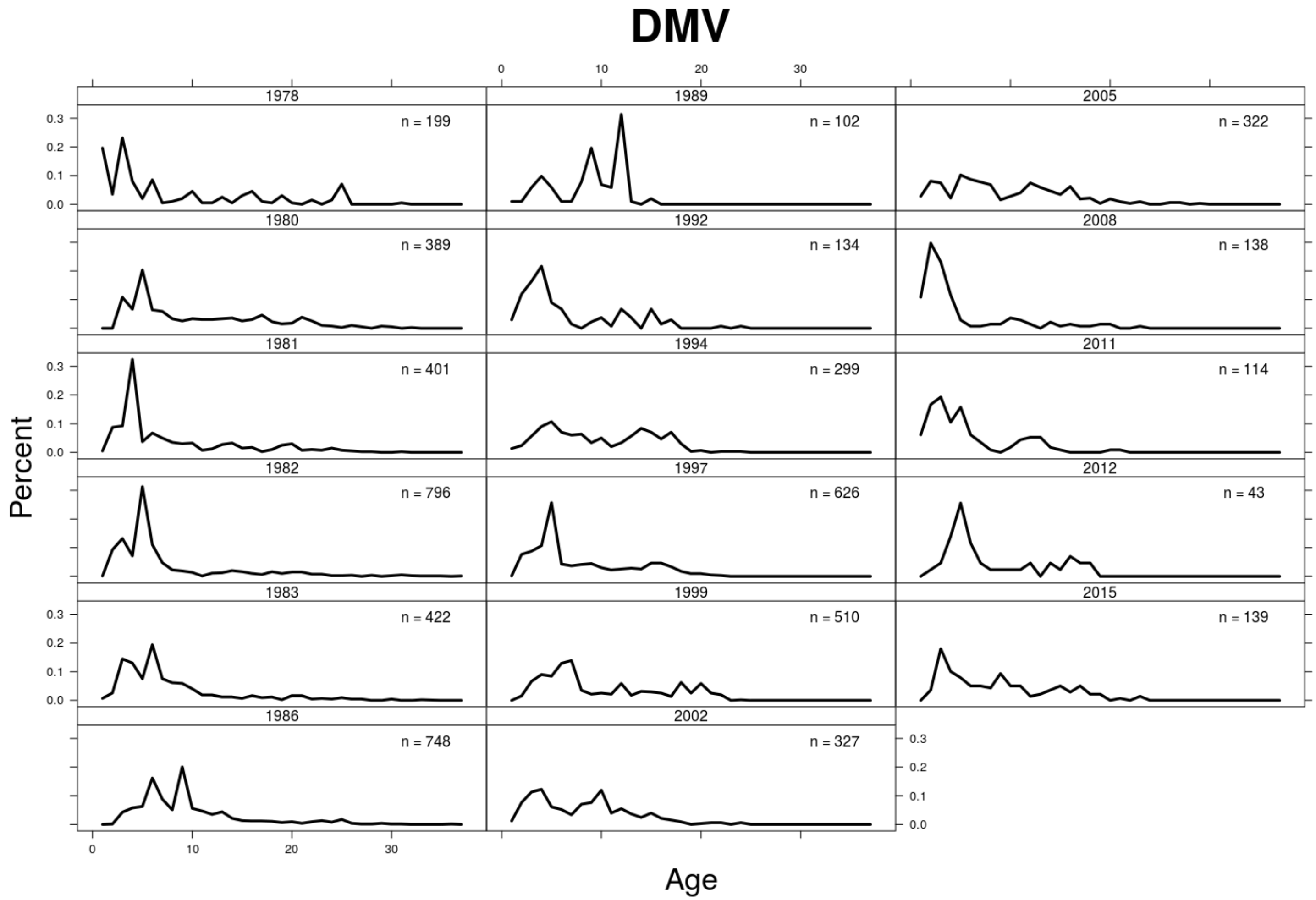



Figure 38: Age composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

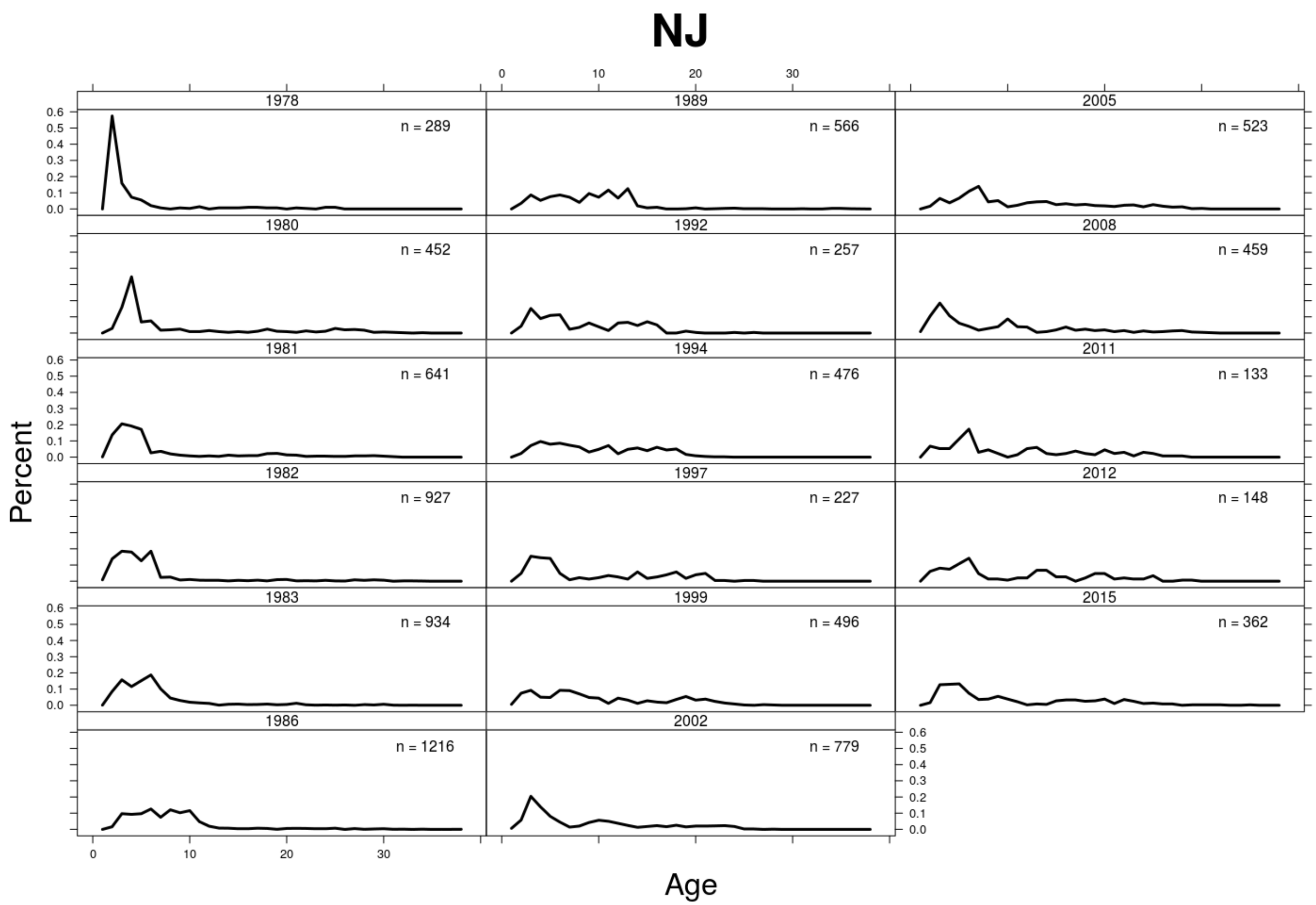



Figure 39: Age composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

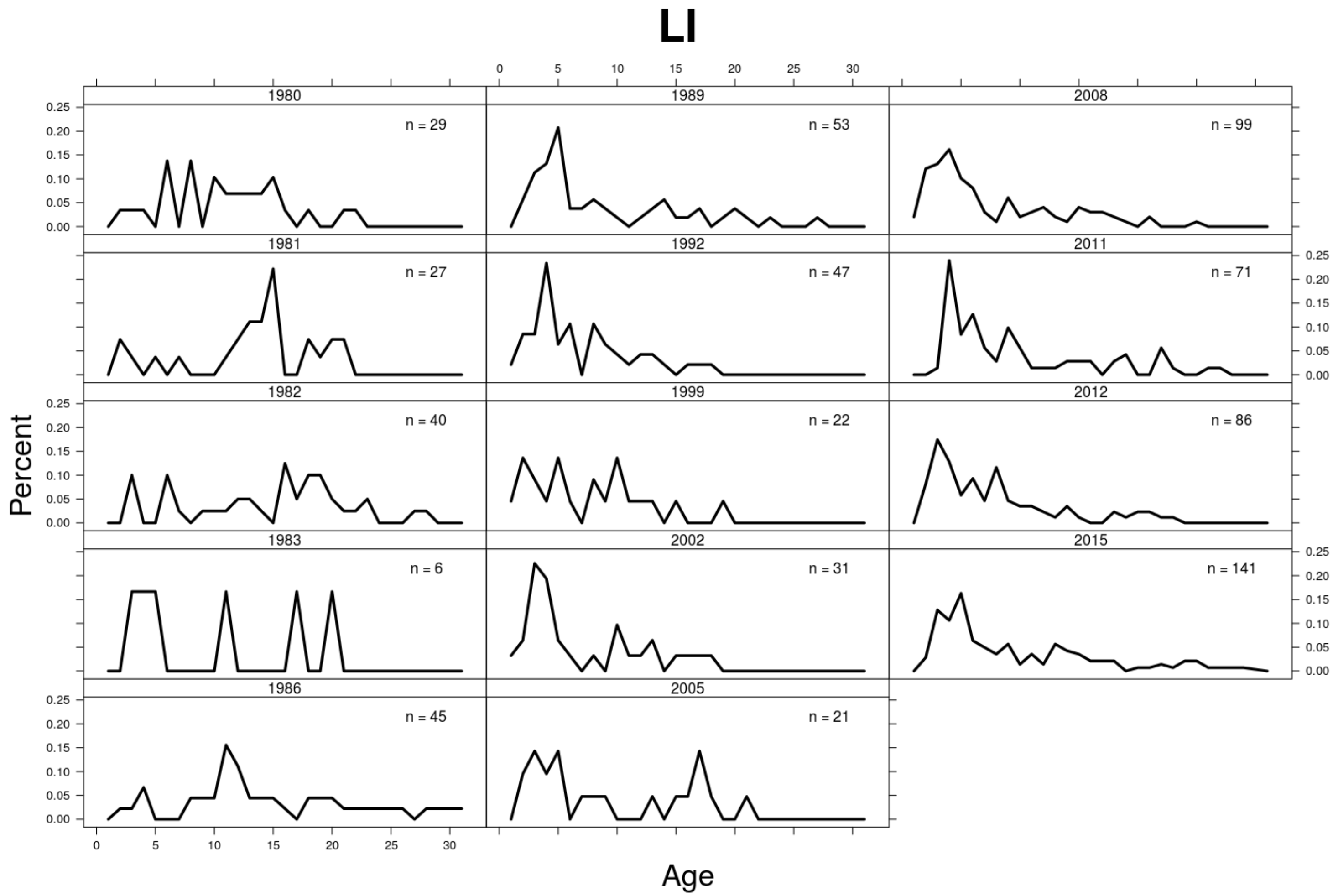



Figure 40: Age composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

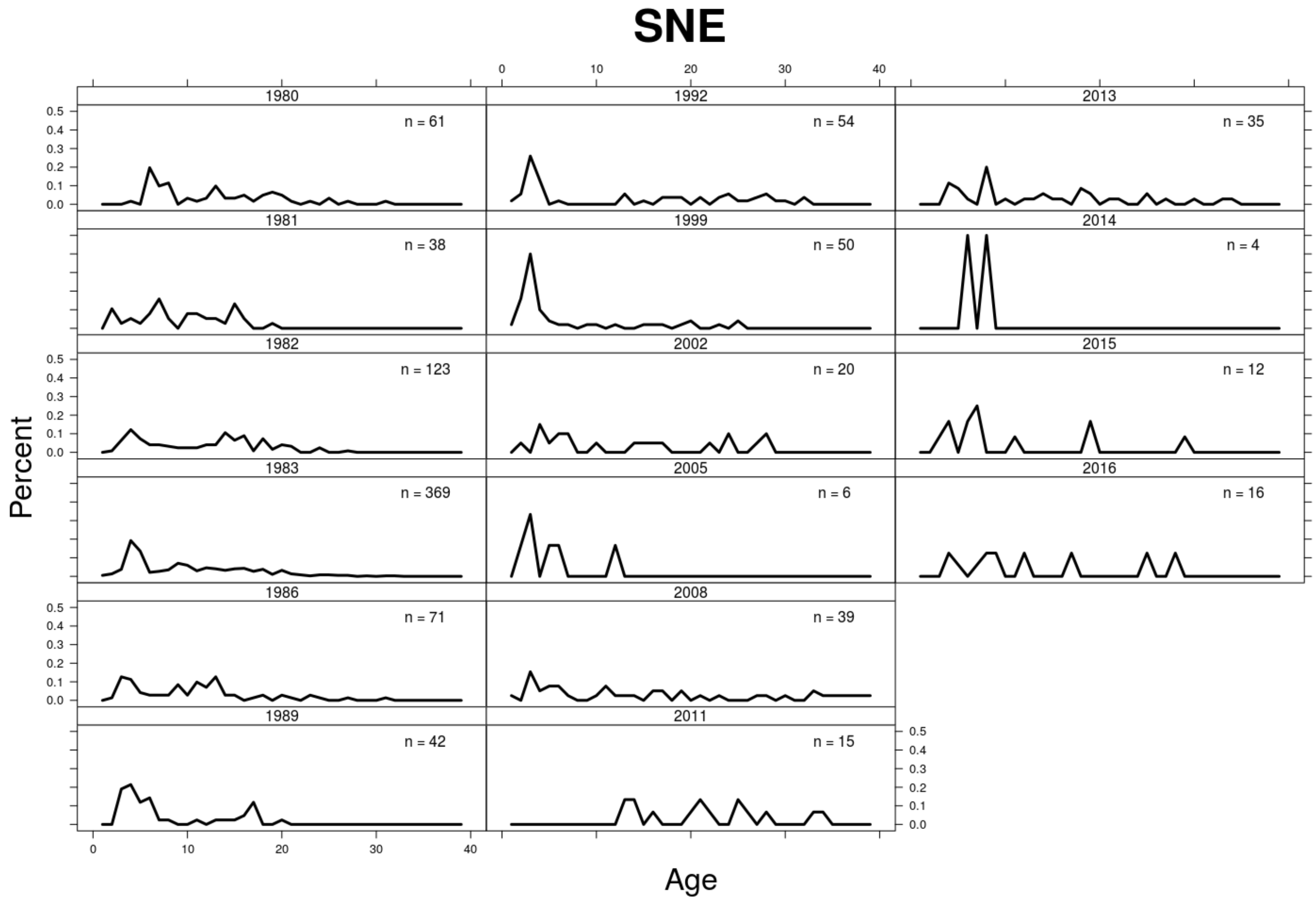



Figure 41: Age composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

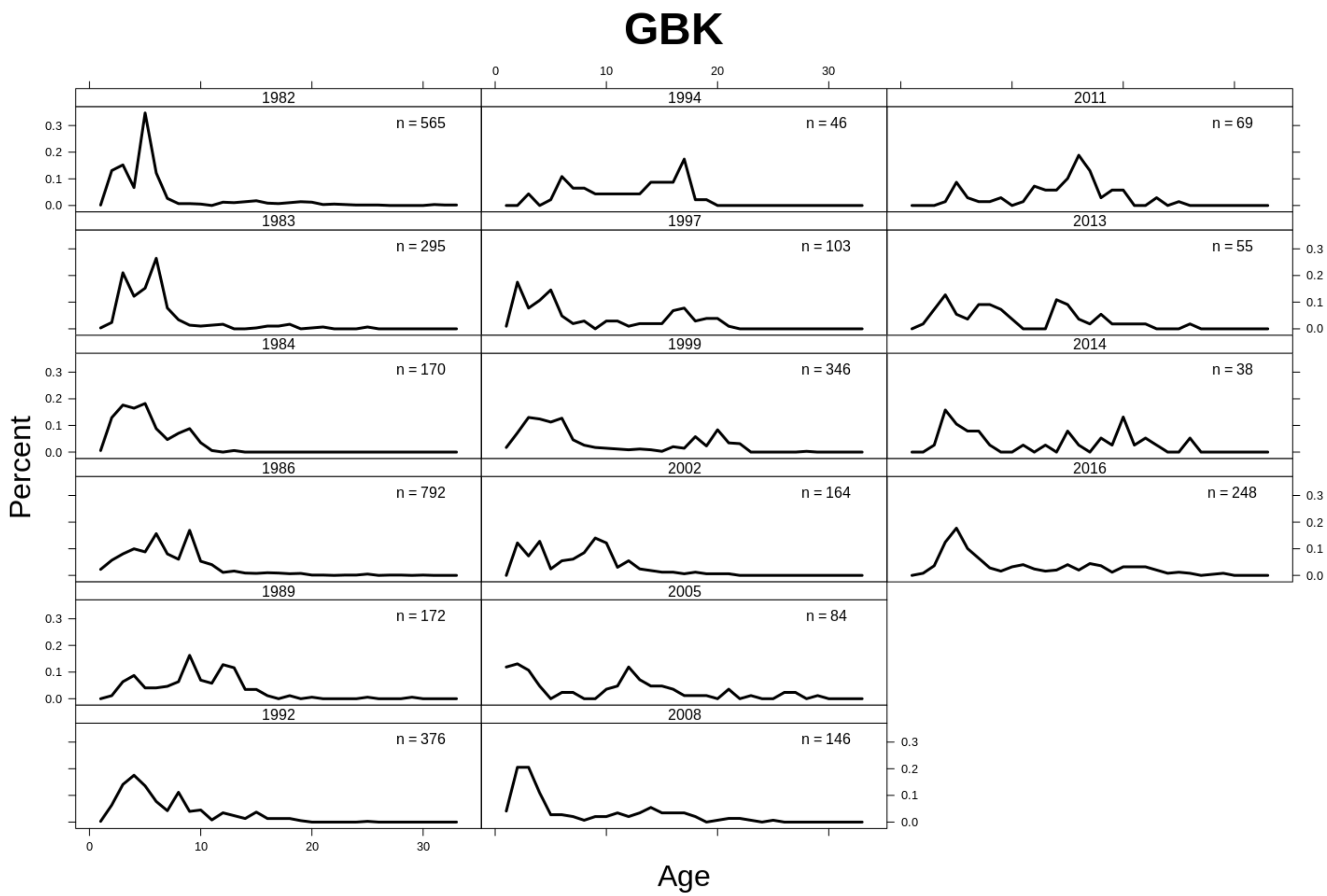



Figure 42: Age composition of Atlantic surfclam in NEFSC surveys in the northern area (GBK), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

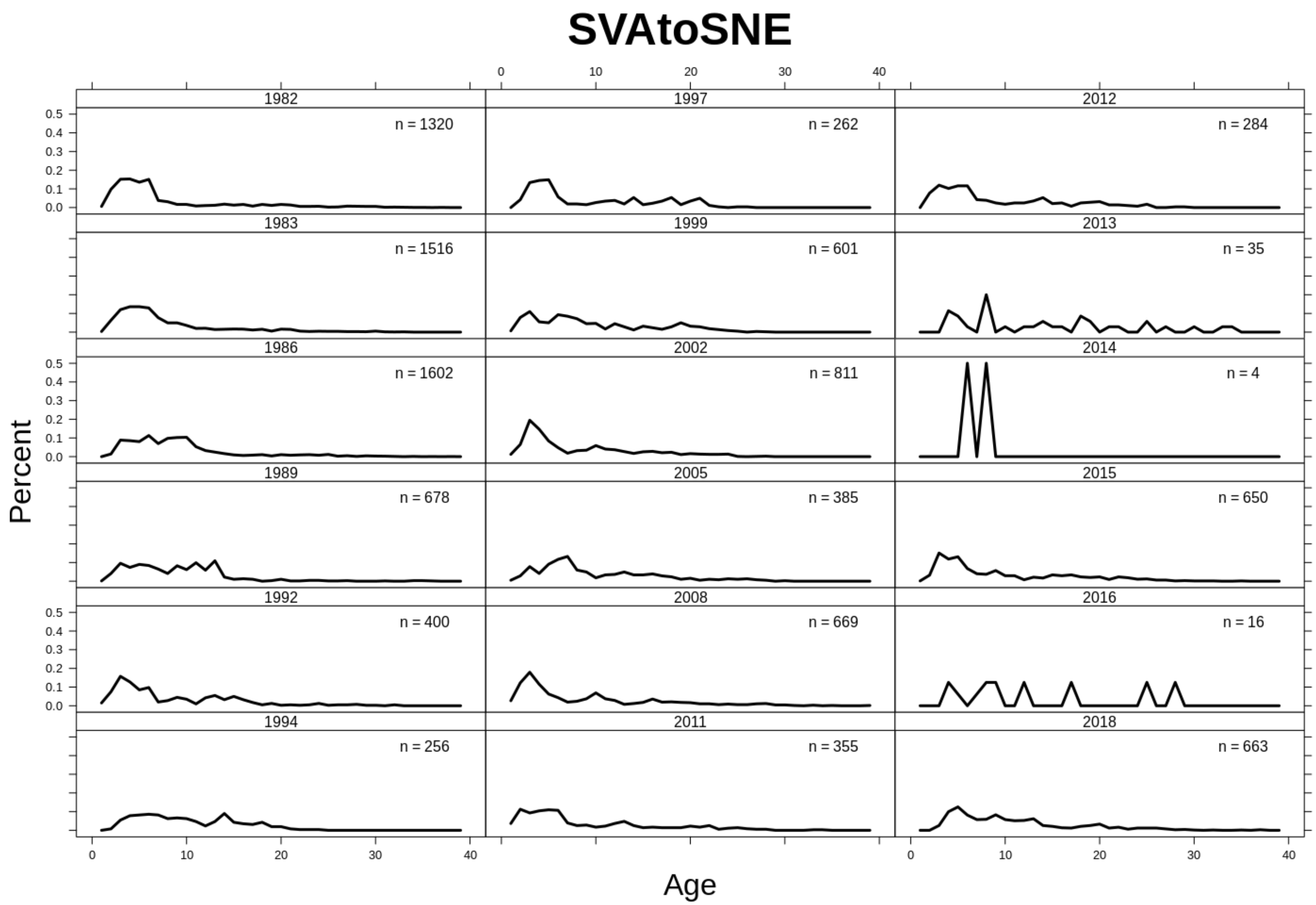



Figure 43: Age composition of Atlantic surfclam in NEFSC surveys in the southern area (SVAtoSNE), including the number of Atlantic surfclam aged in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

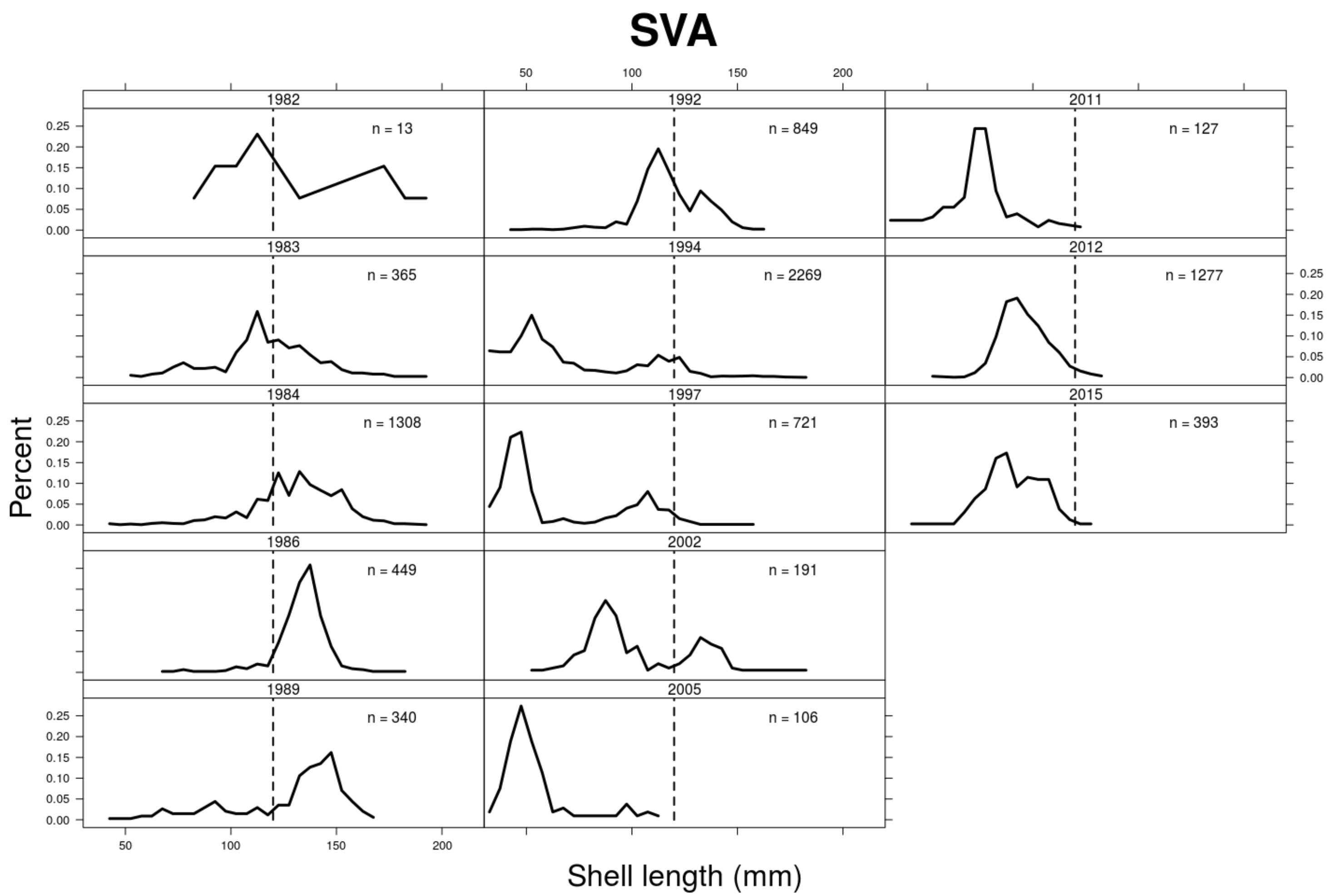



Figure 44: Length composition of Atlantic surfclam in NEFSC surveys in SVA, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

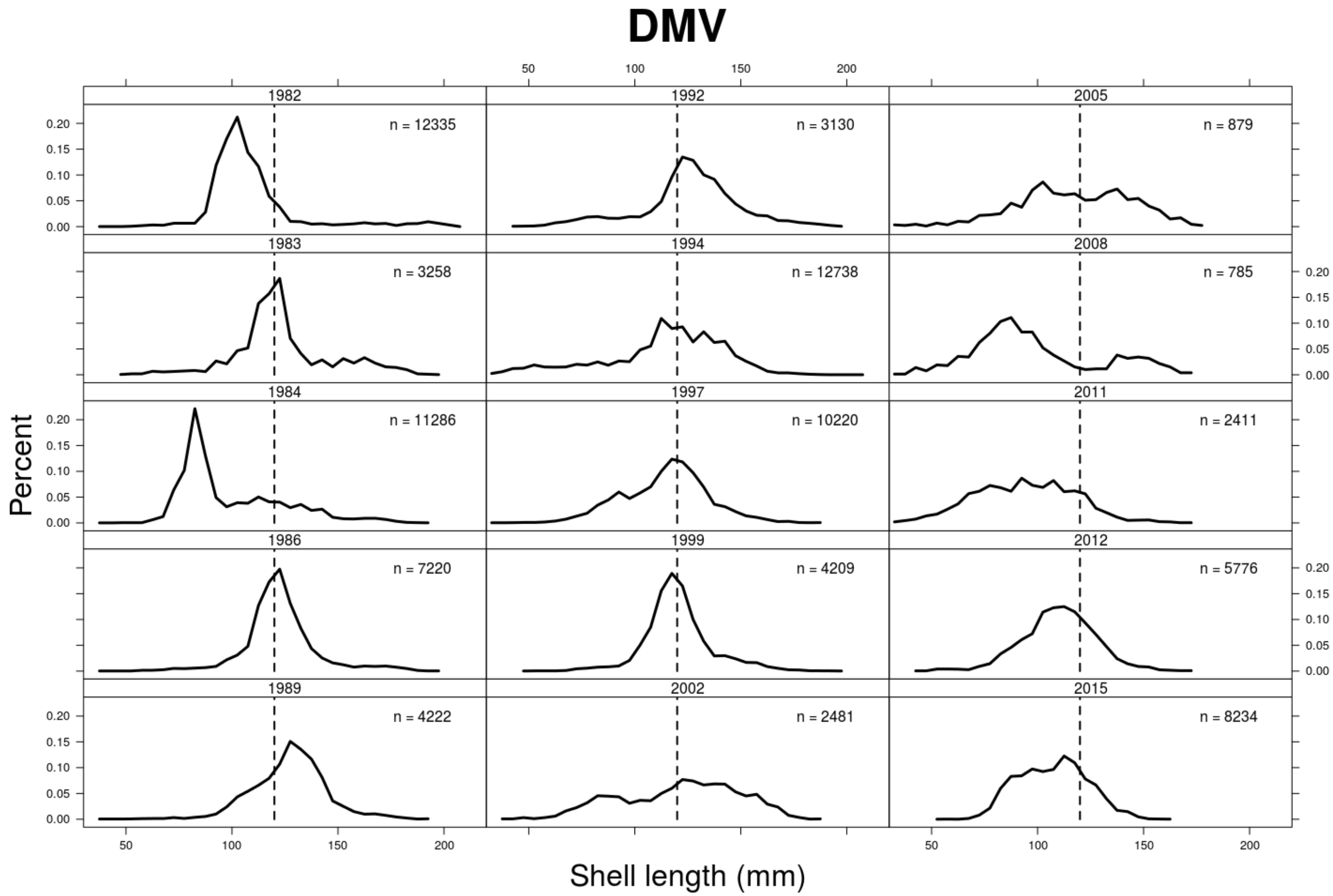



Figure 45: Length composition of Atlantic surfclam in NEFSC surveys in DMV, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

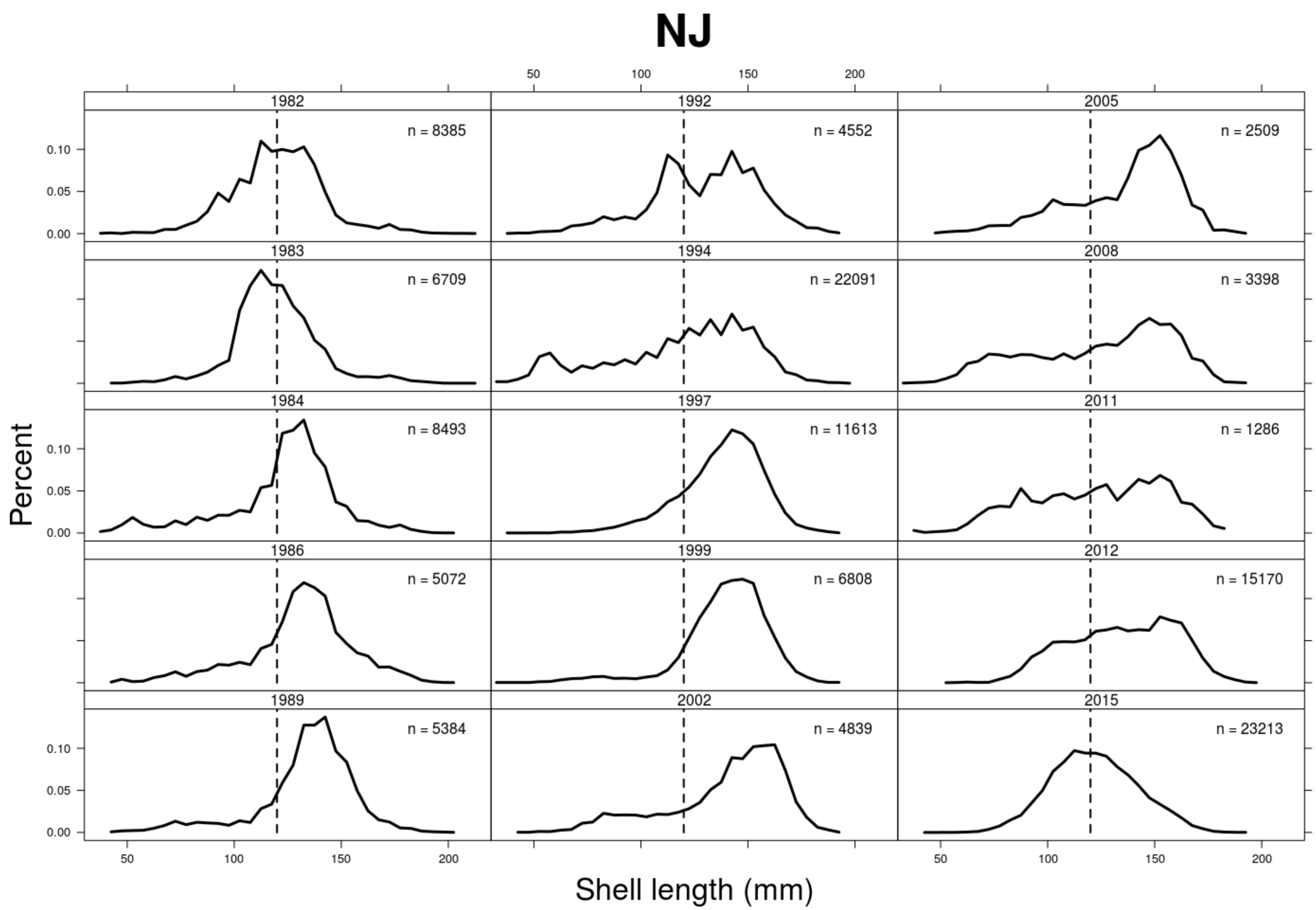



Figure 46: Length composition of Atlantic surfclam in NEFSC surveys in NJ, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

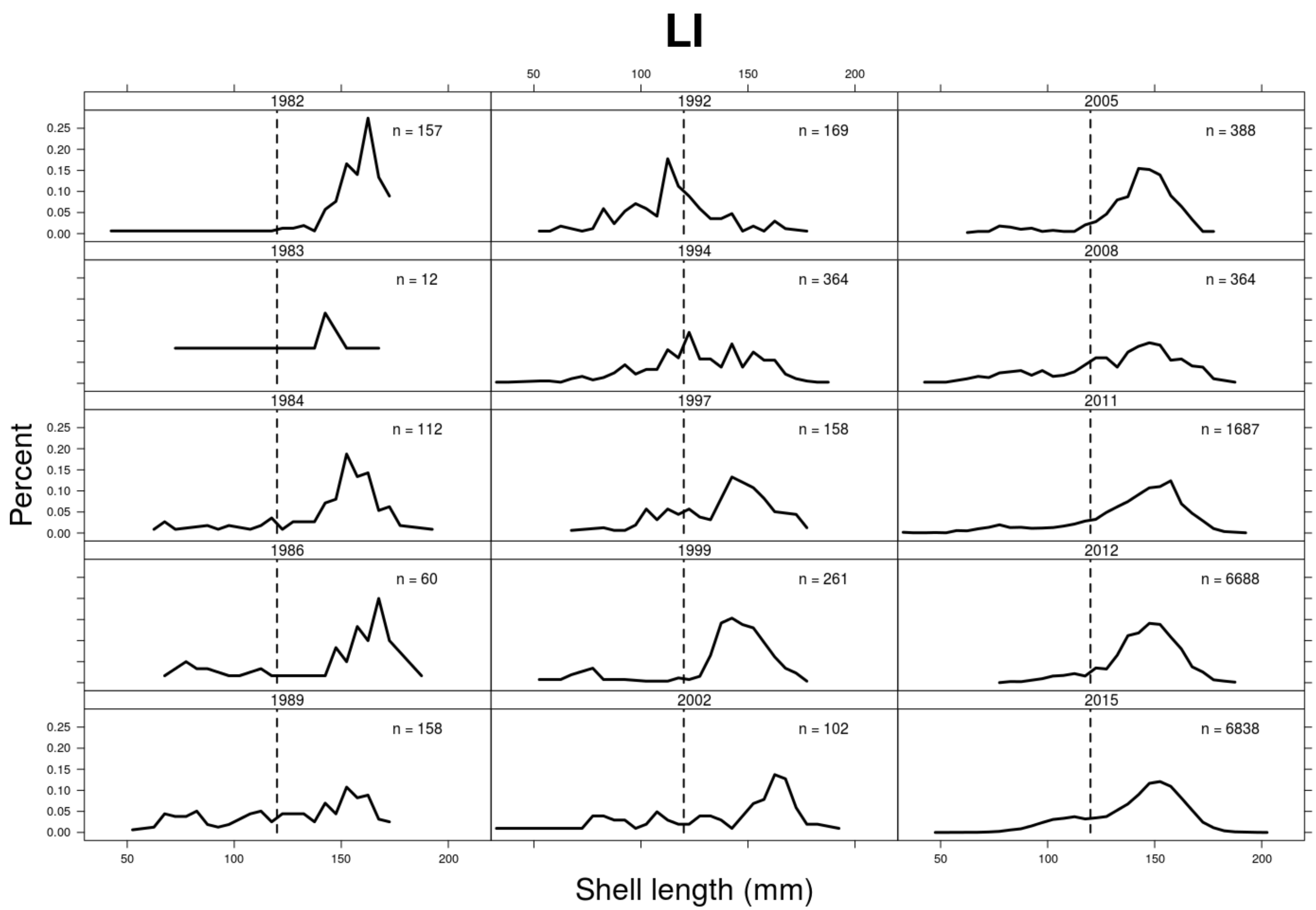



Figure 47: Length composition of Atlantic surfclam in NEFSC surveys in LI, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

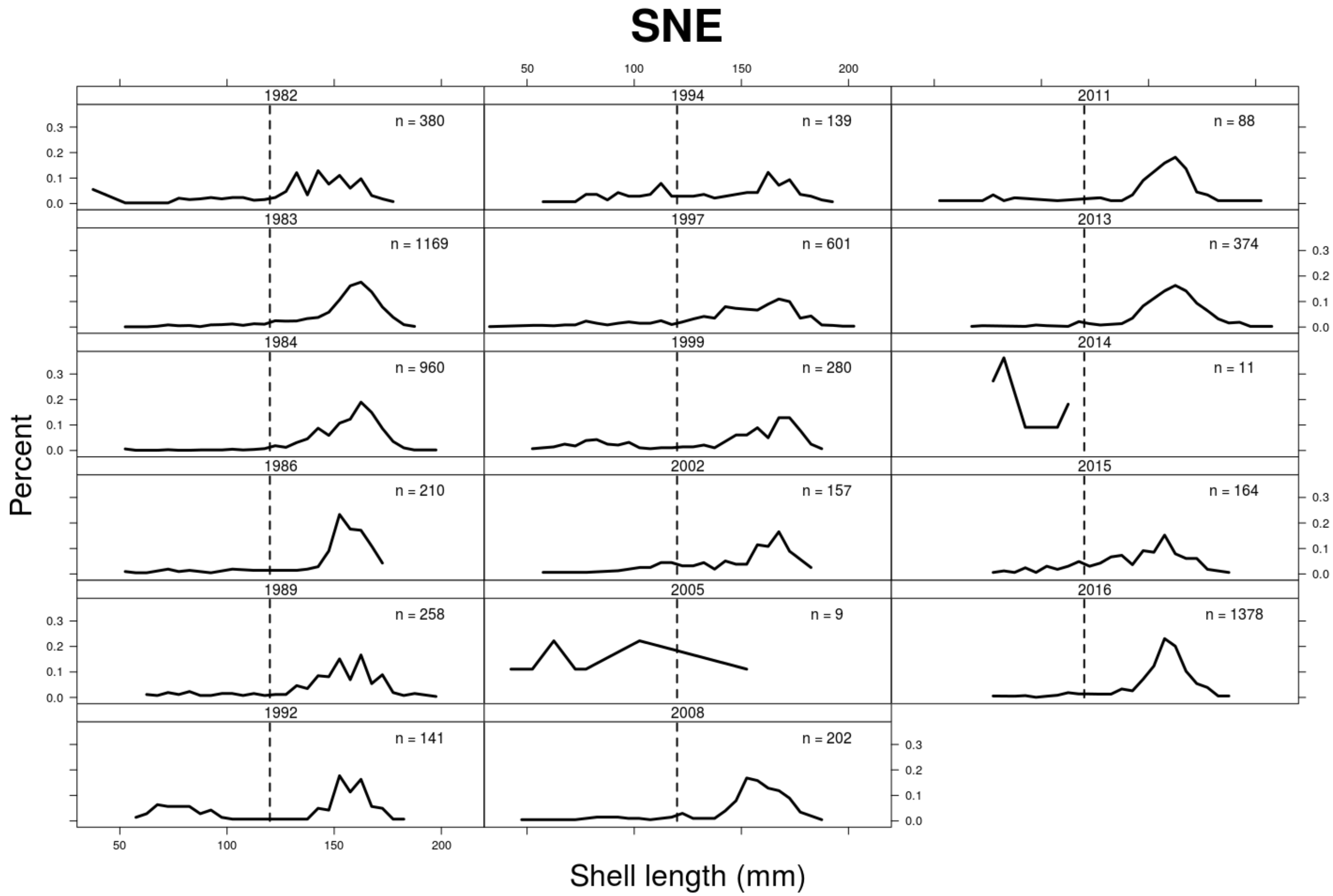



Figure 48: Length composition of Atlantic surfclam in NEFSC surveys in SNE, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

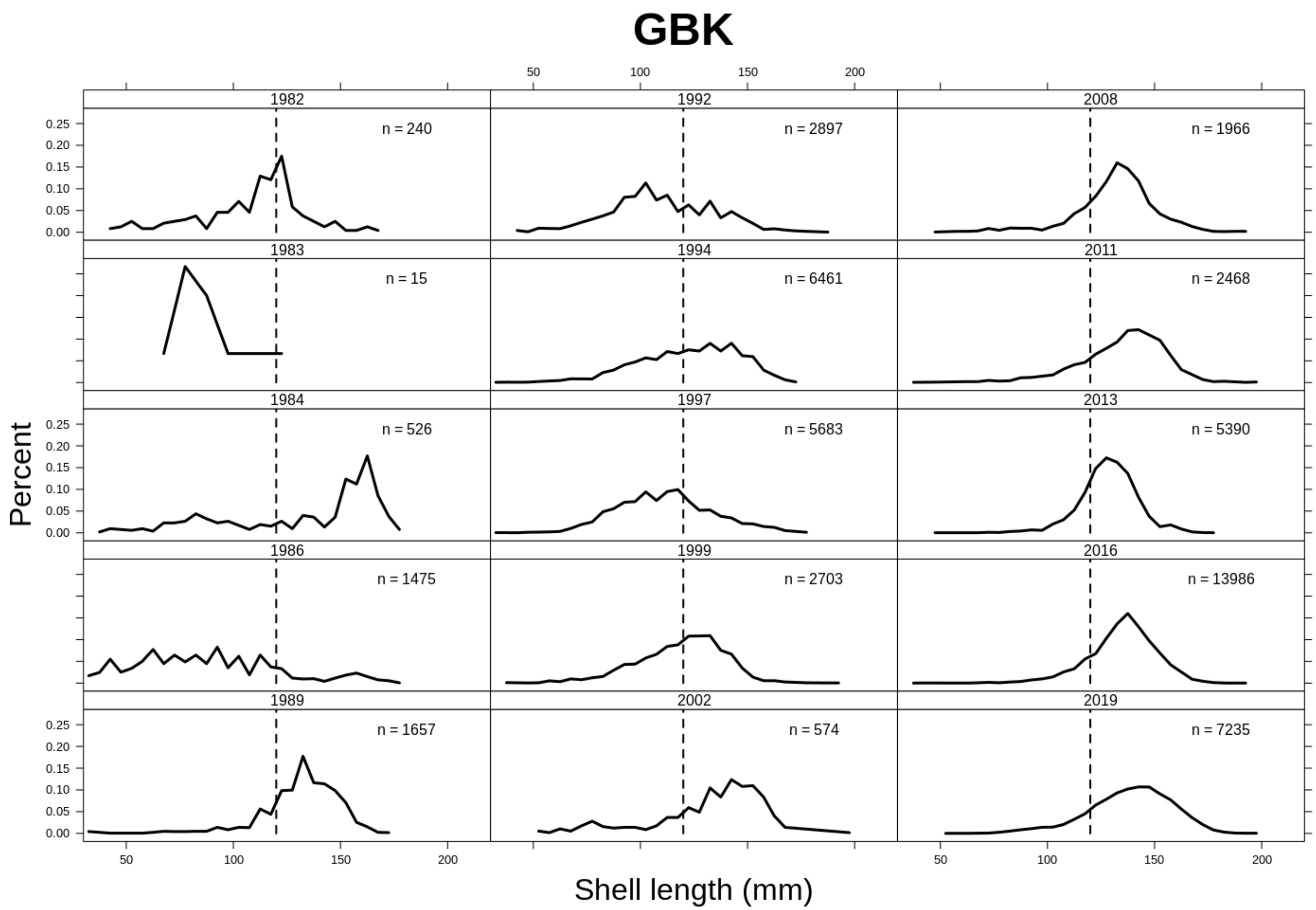



Figure 49: Length composition of Atlantic surfclam in NEFSC surveys in GBK, including the number of Atlantic surfclam measured in each year (n). The size selectivity of the survey changed after 2011 when the survey was switched to a commercial platform. Composition data from before 2011 are not directly comparable to data since 2012.

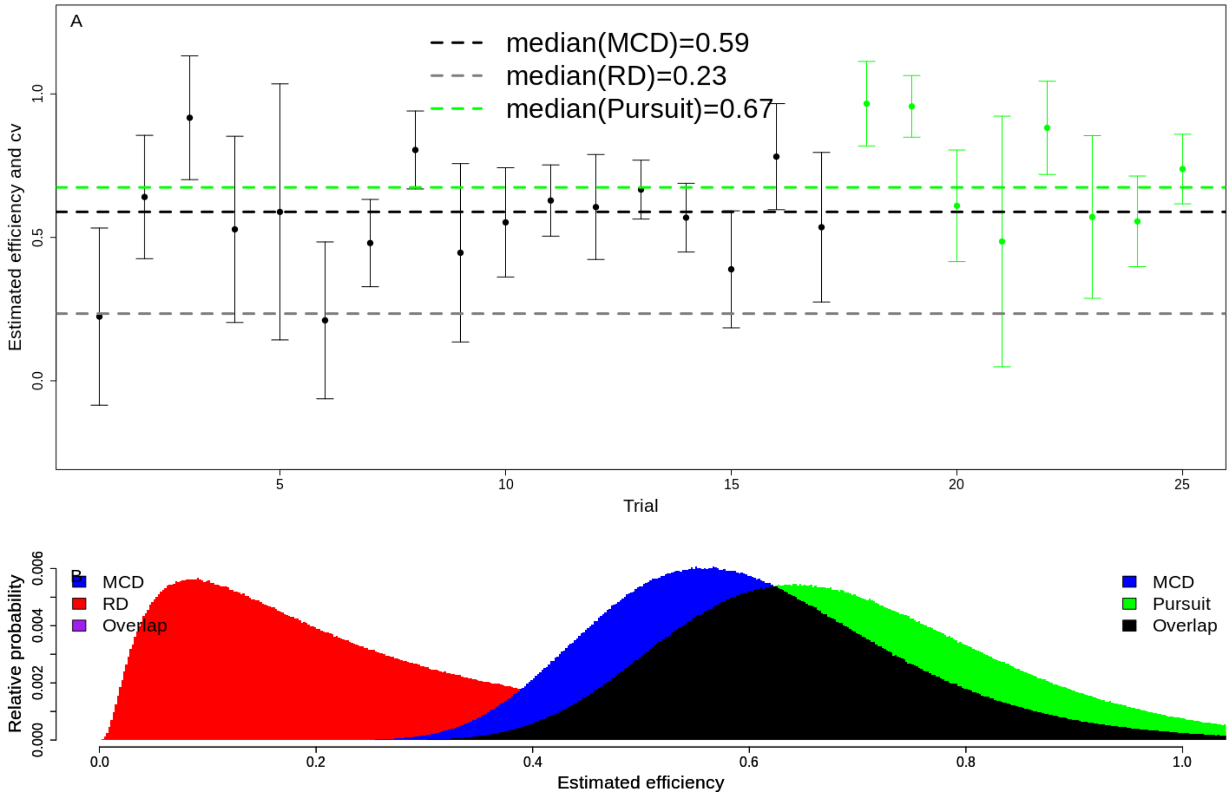



Figure 50: Panel A) Individual modified commercial dredge (MCD) capture efficiency estimates with coefficients of variation compared to median values for the MCD and the survey dredge used from the research vessel (RD) as well as the specific dredge used on the current survey (Pursuit). Panel B) A comparison of median values values incoprorating the pooled cv for each dredge where each is shown as a truncated lognormal distribution. The MCD and Pursuit dredge had higher and more precisely estimated capture efficiency than the RD.

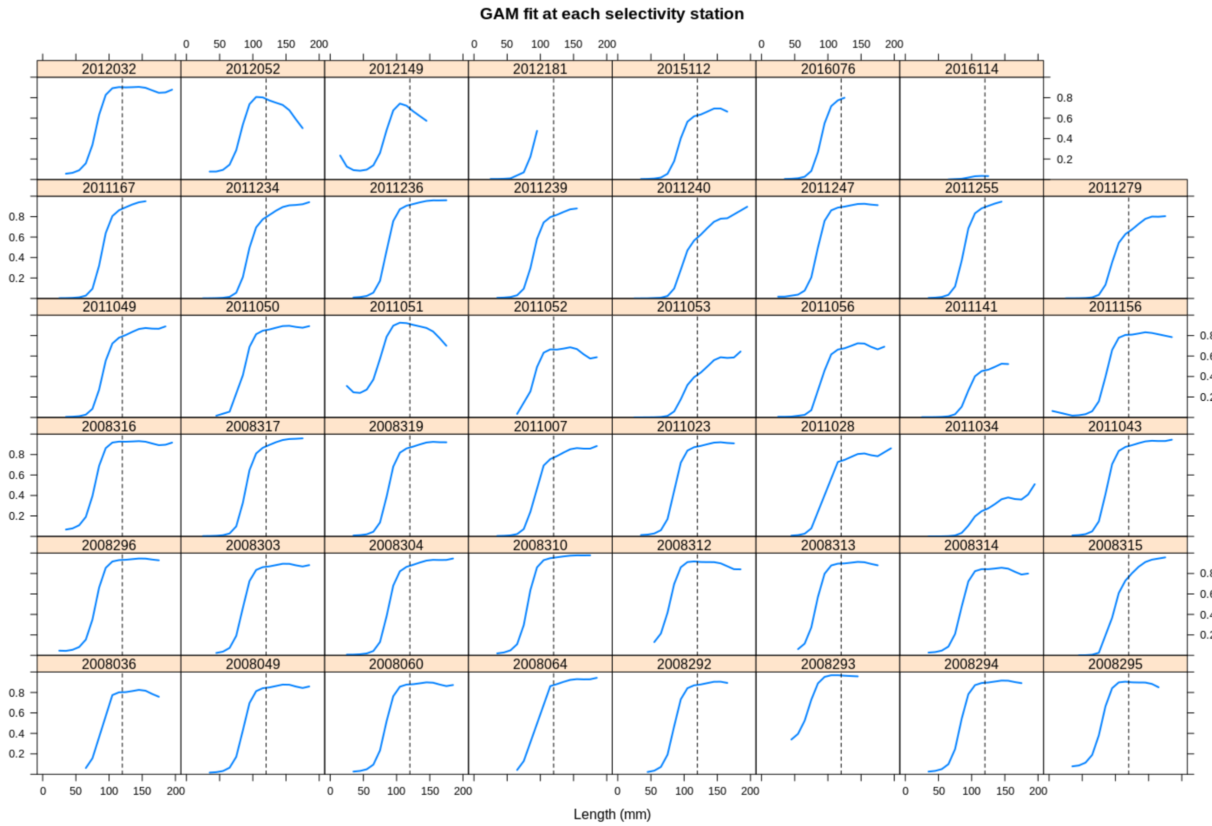



Figure 51: GAM fits to the selectivity data for Atlantic surfclam from field experiments (MCD compared to lined dredge) by year and station. The plots generally indicate flat topped selectivity curves.

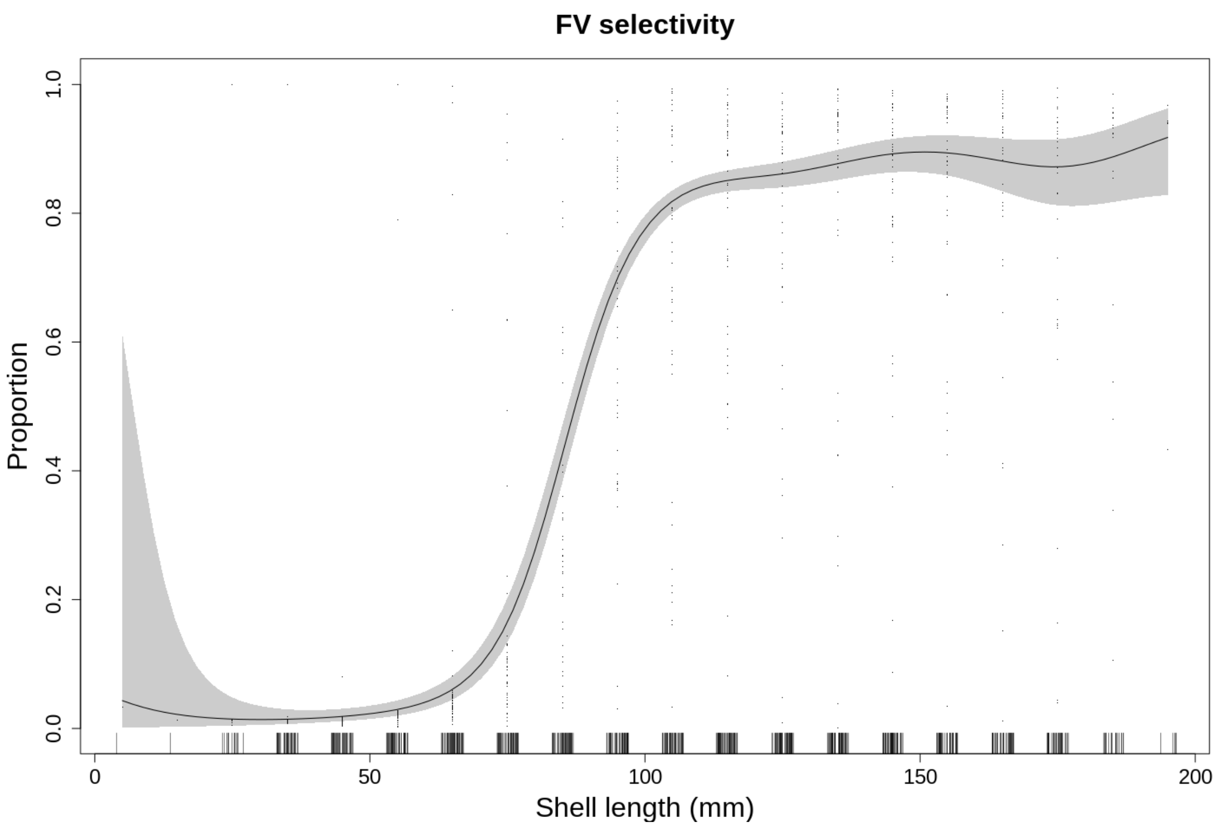



Figure 52: The GAM fit to all the selectivity data for Atlantic surfclam in the MCD in all years. The best (by AIC) model included random effects in both the intercept and spline over length. The data density is shown in the rug plot along the horizontal axis and relative confidence is represented by the shaded region.

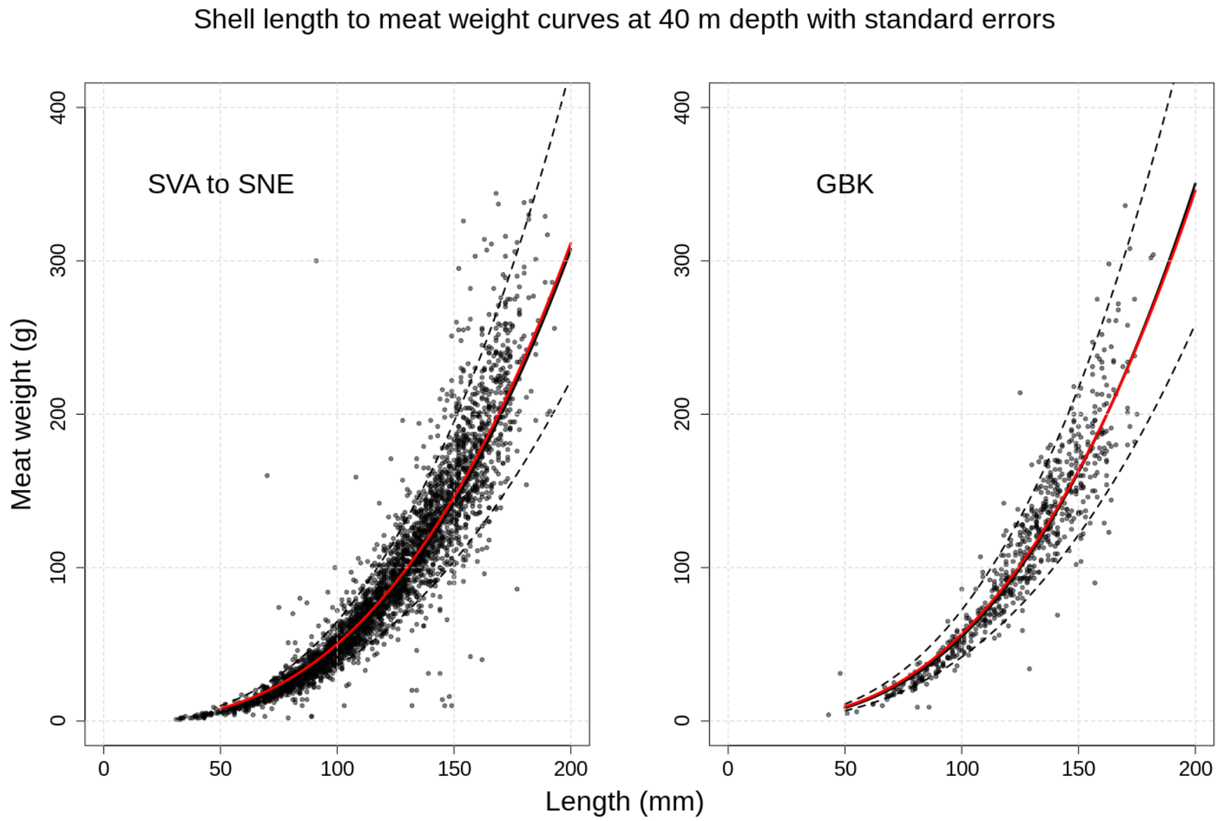



Figure 53: Broad scale area differences in allometric relationships for Atlantic surfclam based on survey data. The same depth (40 m) was used to generate the curves for each area. The $95\%$ confidence regions are represented by the dotted line.

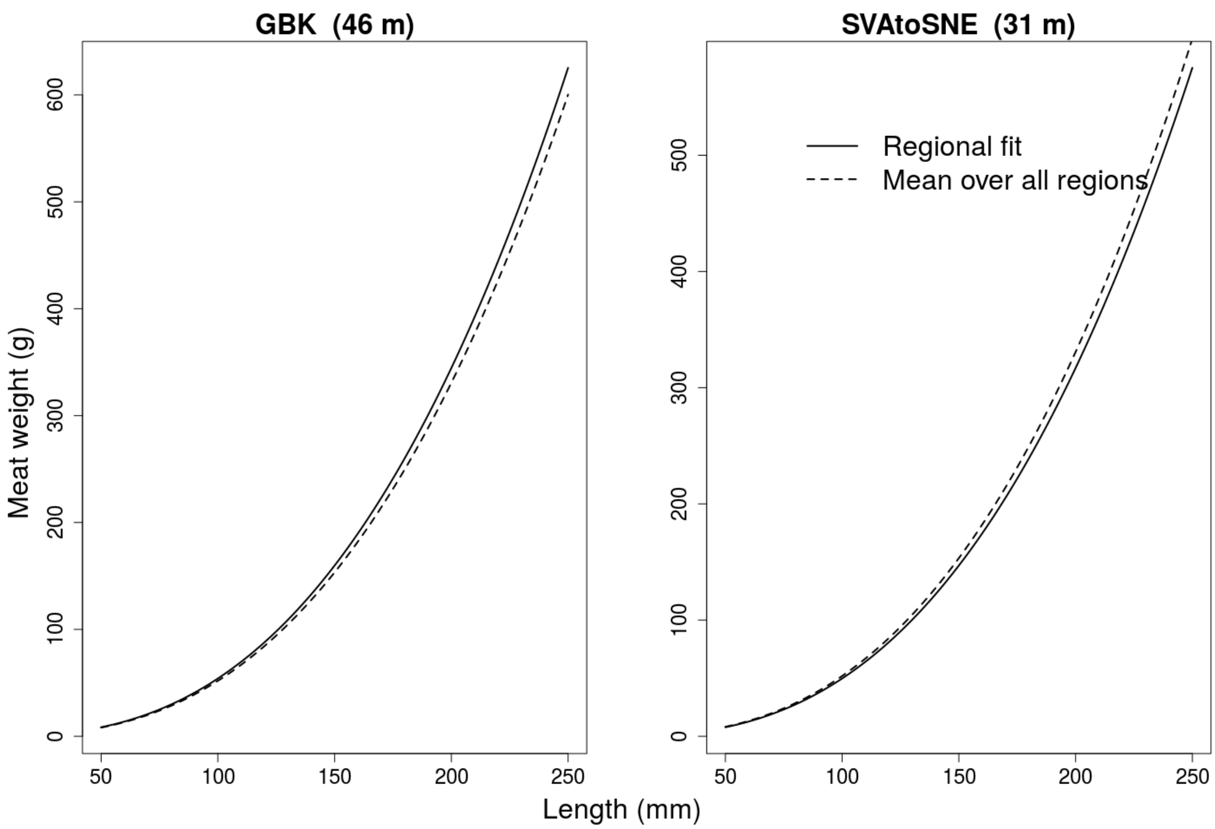



Figure 54: Regional differences in allometric relationships for Atlantic surfclam based on survey data. The median depth in each region was used to generate the curves. The global mean is represented by the dotted line.

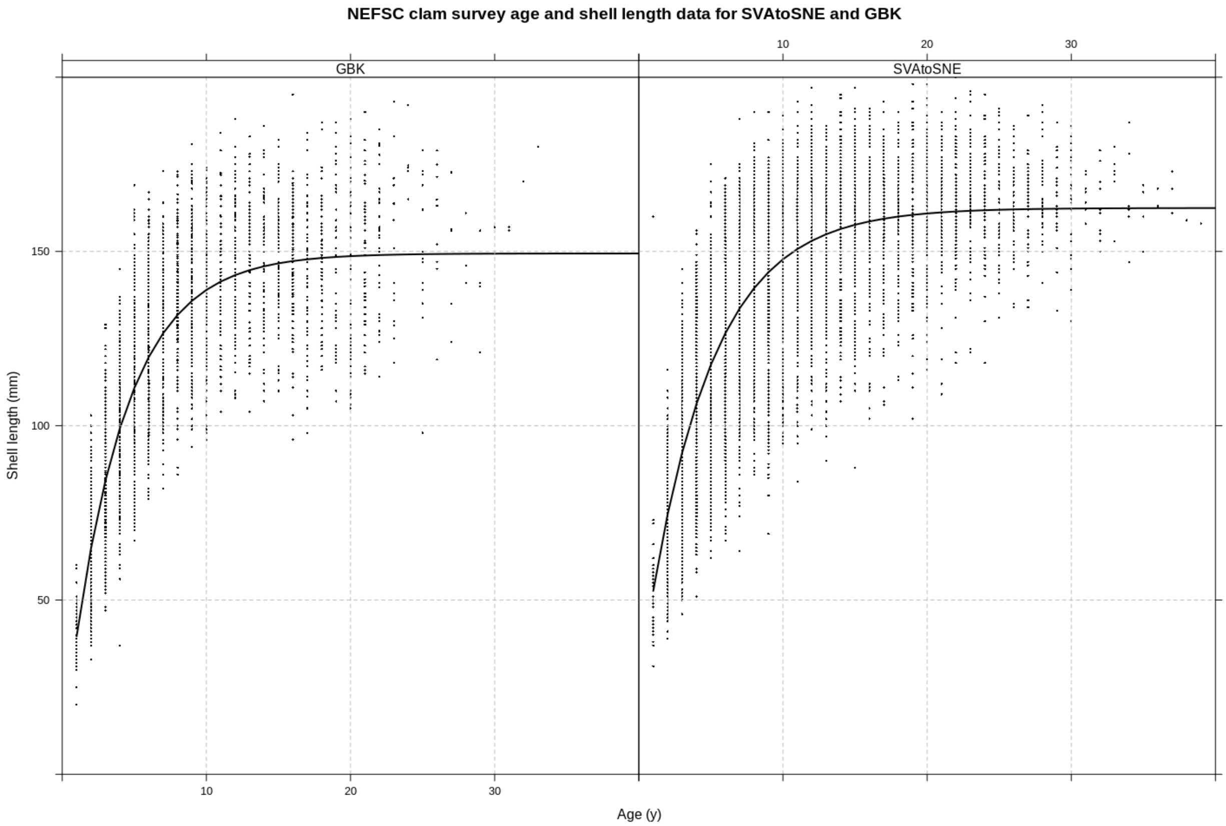



Figure 55: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different areas.

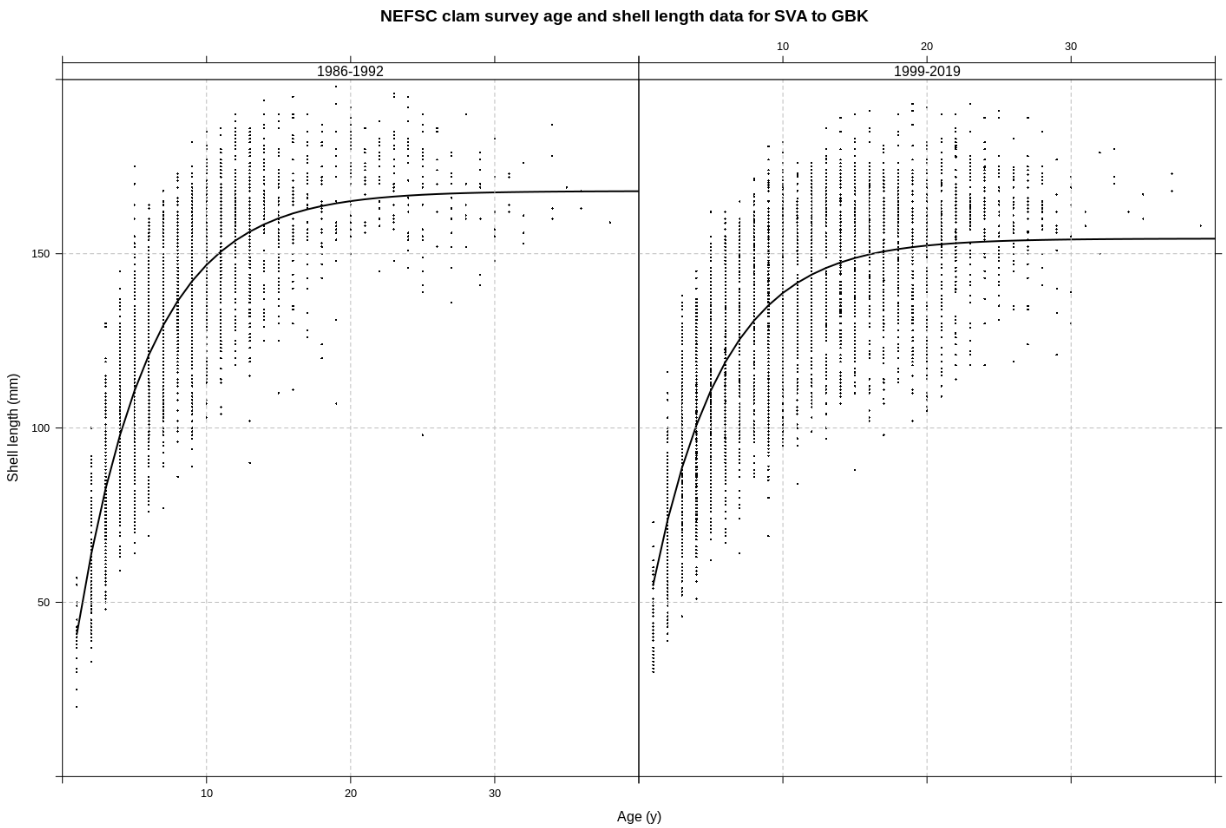



Figure 56: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve in different eras for the whole stock.

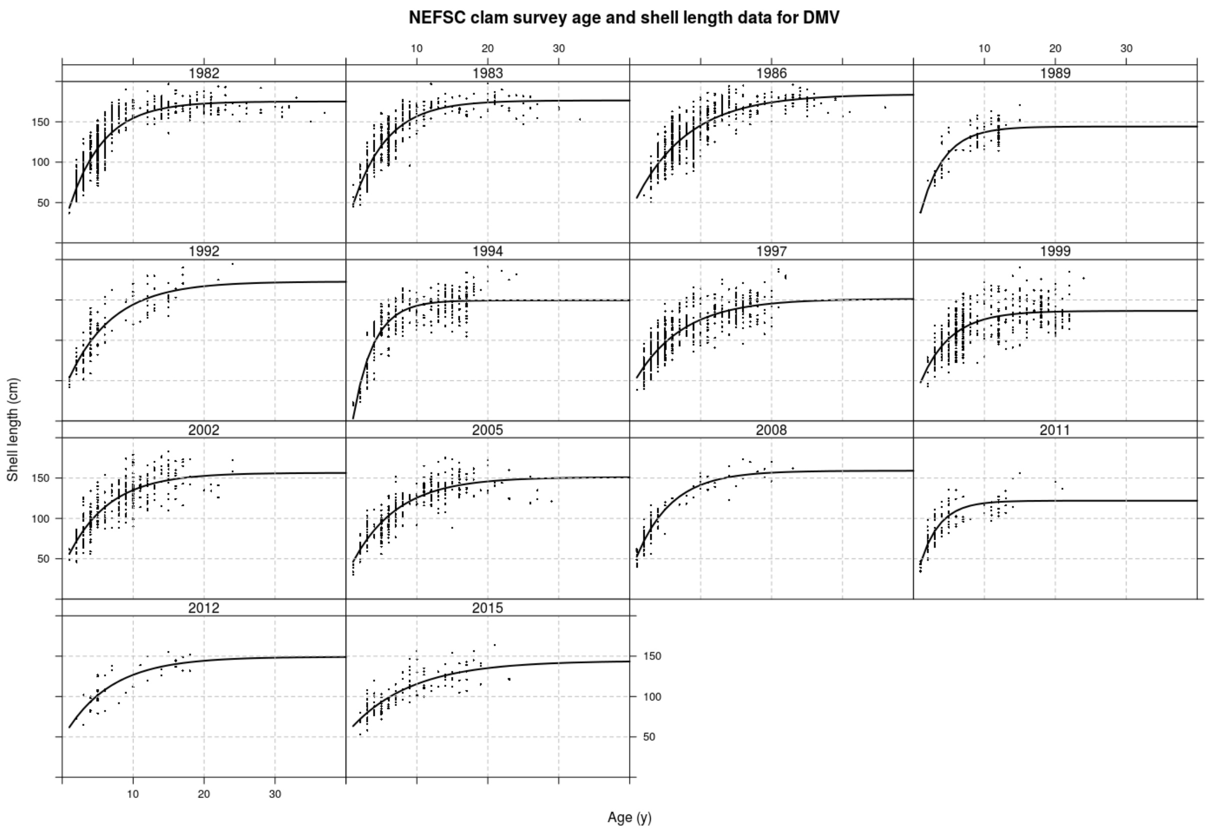



Figure 57: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the DMV region in each survey year.

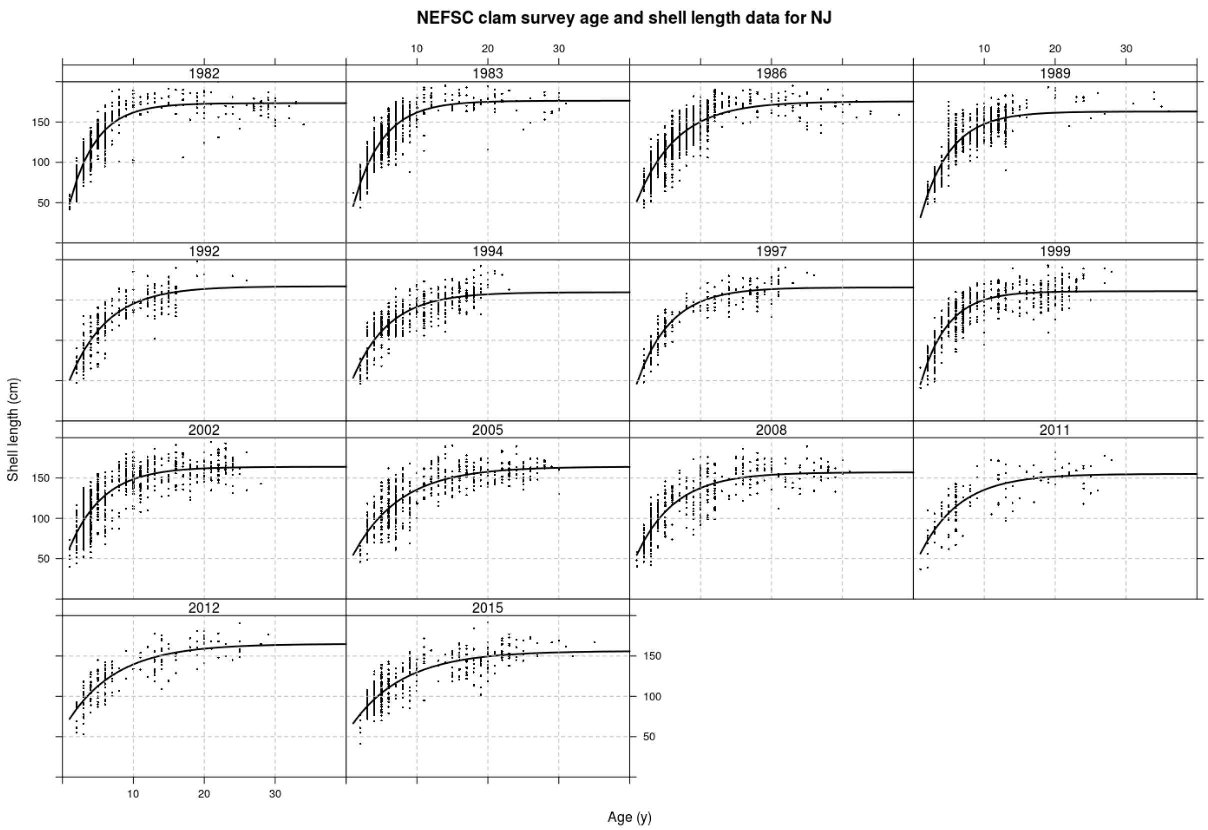



Figure 58: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the NJ region in each survey year.

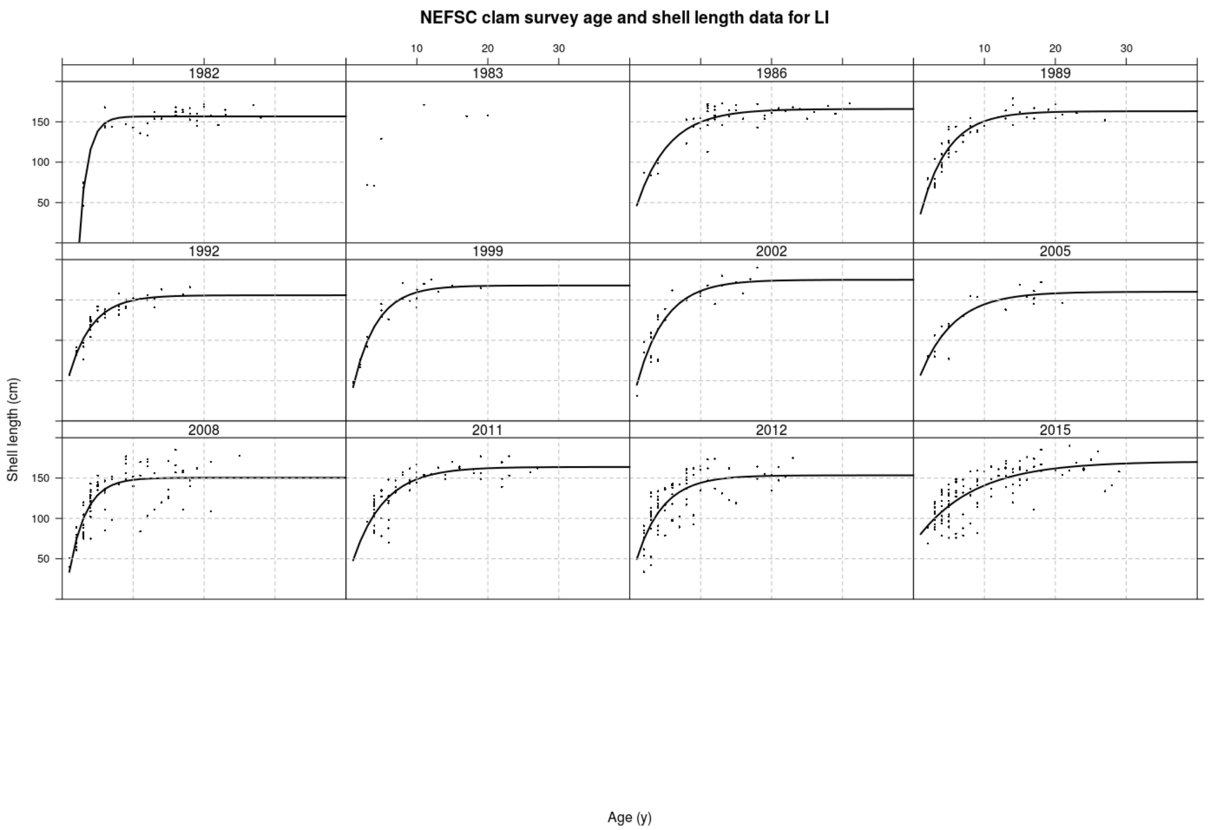



Figure 59: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the LI region in each survey year.

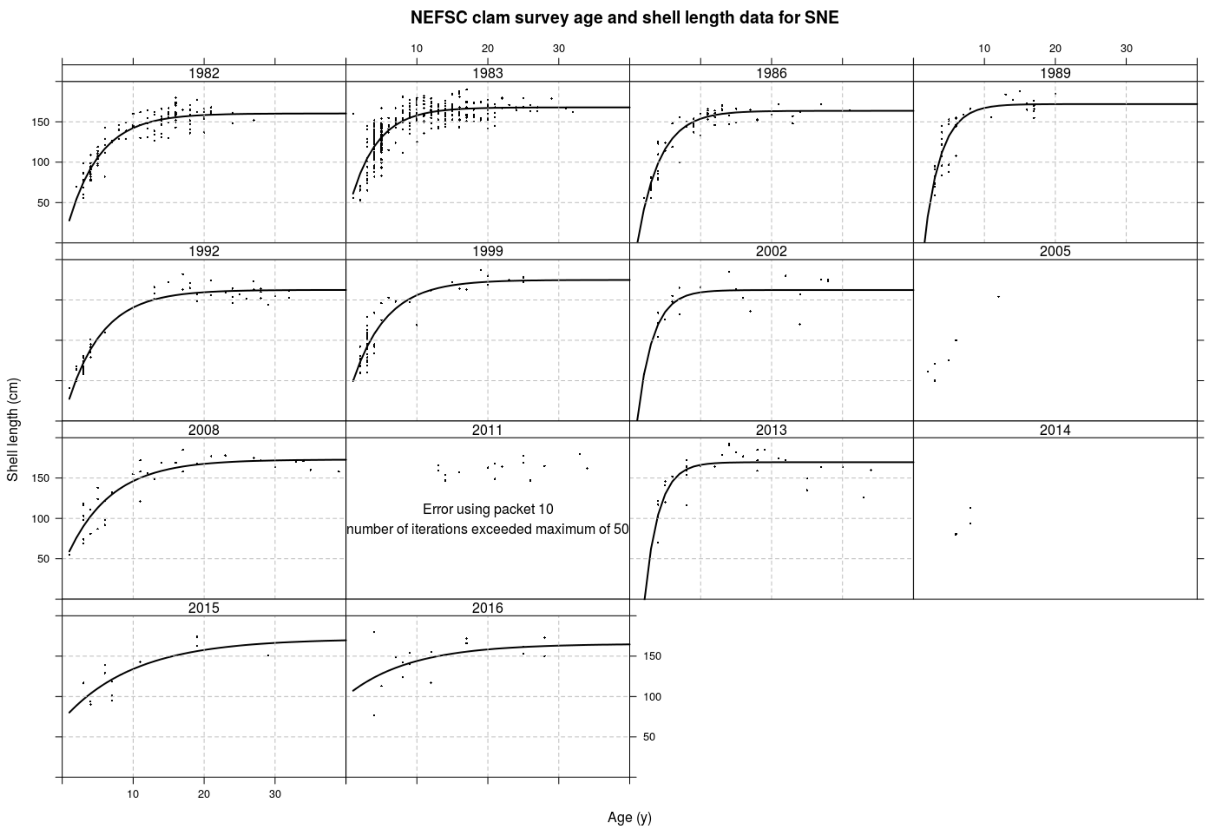



Figure 60: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the SNE region in each survey year.

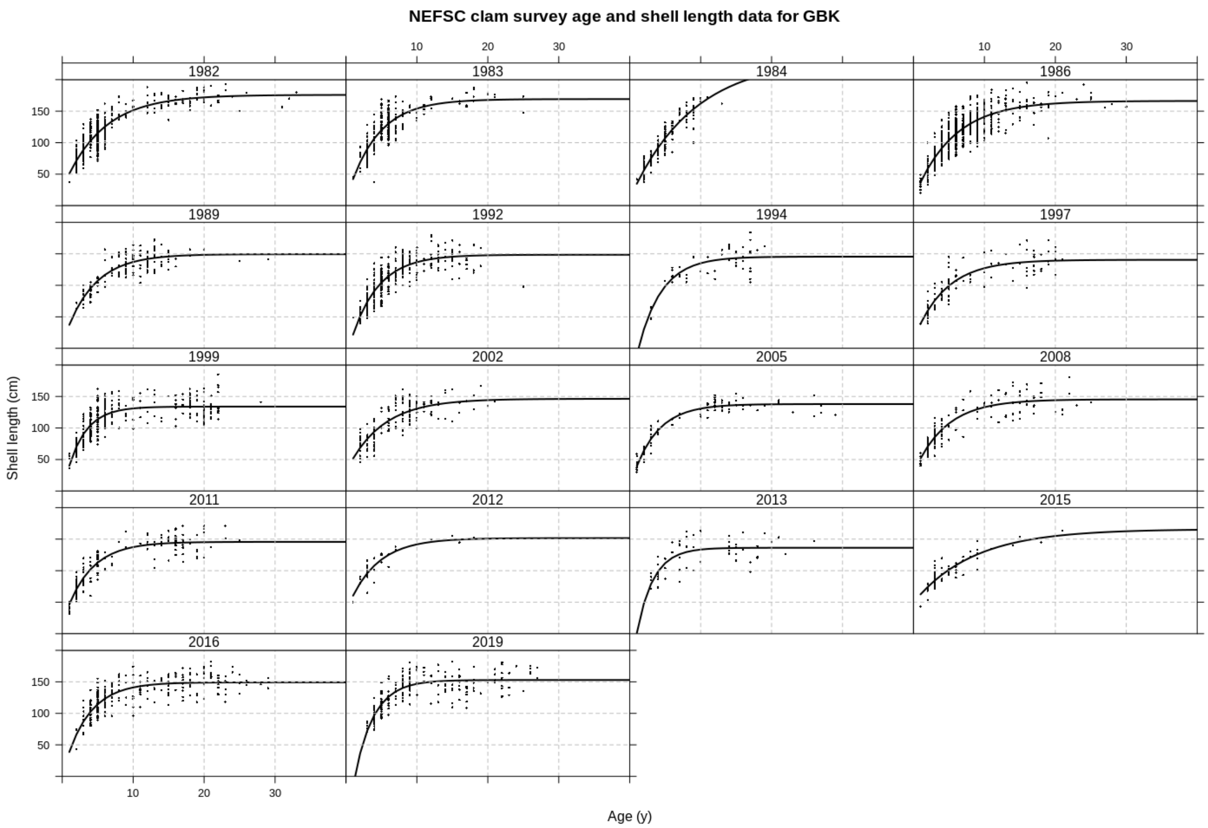



Figure 61: Age vs. length for Atlantic surfclam based on survey data with fitted Von Bertalanffy growth curve for the GBK region in each survey year.

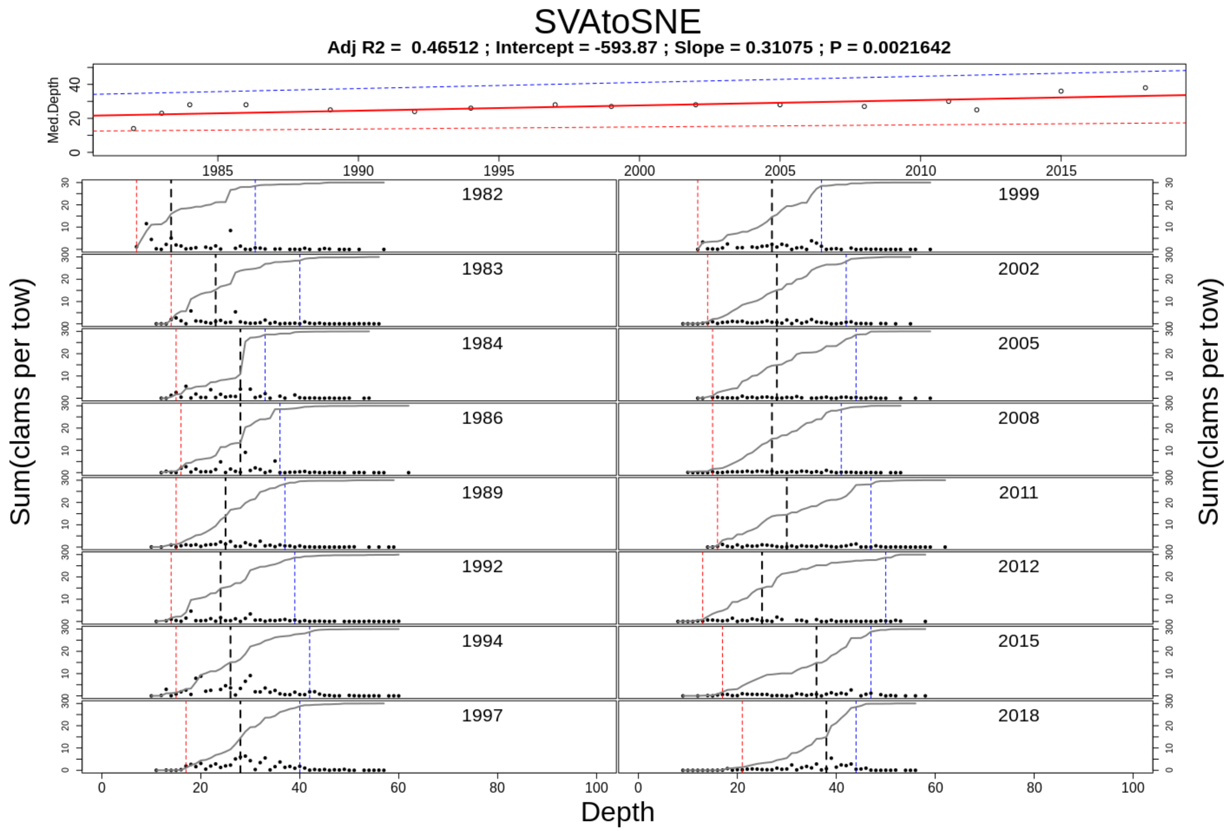



Figure 62: Total surfclams caught at depth by year in SVAtoSNE. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

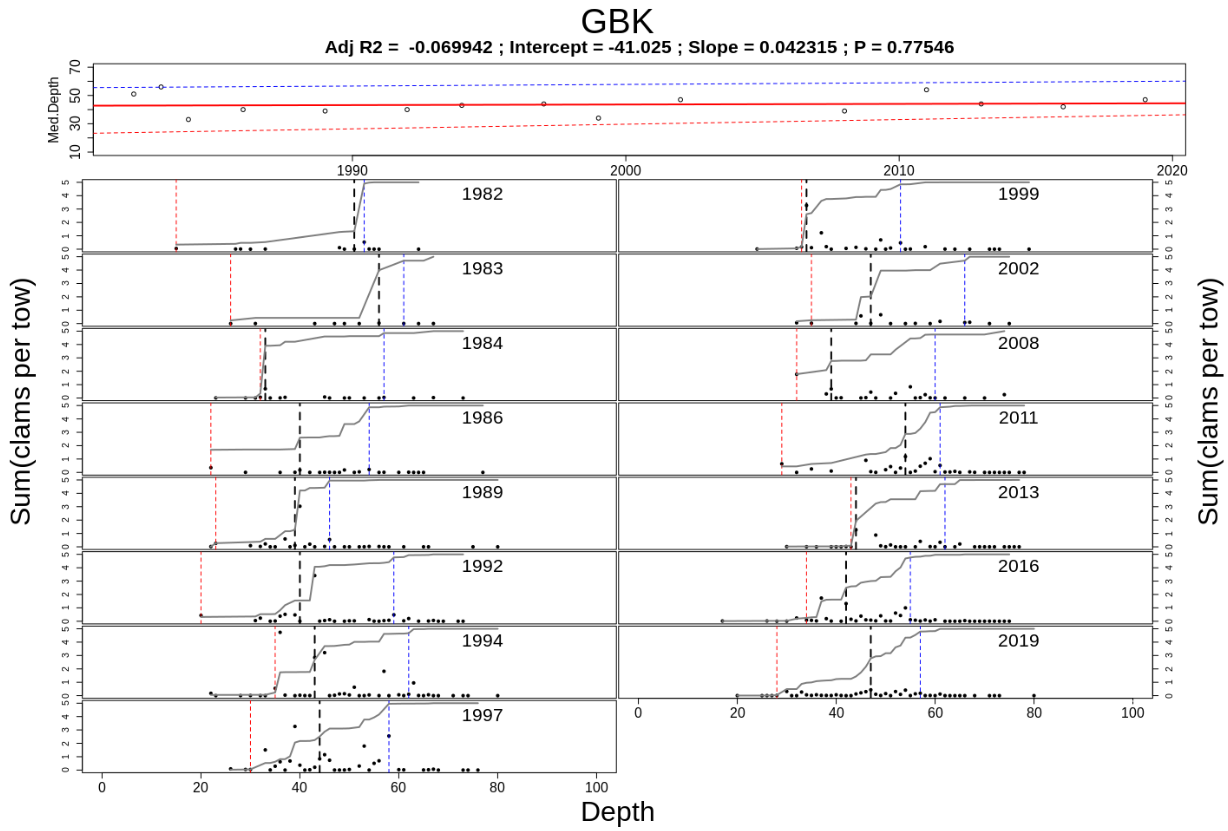



Figure 63: Total surfclams caught at depth by year in GBK. The points are clams caught aggregated by depth and the gray line is the cummulative sum of clams caught at depth. The dashed vertical line is the depth at which half of the cummulative total clams caught in that survey were taken. If the dashed vertical line is further to the right it indicates that more clams were caught in deeper water in that year. The top panel is a simple linear regression of median depth (the dashed vertical lines in each annual plot) over time. A positive slope indicates that a higher proportion of the total clams in a region were caught in deeper water in recent years.

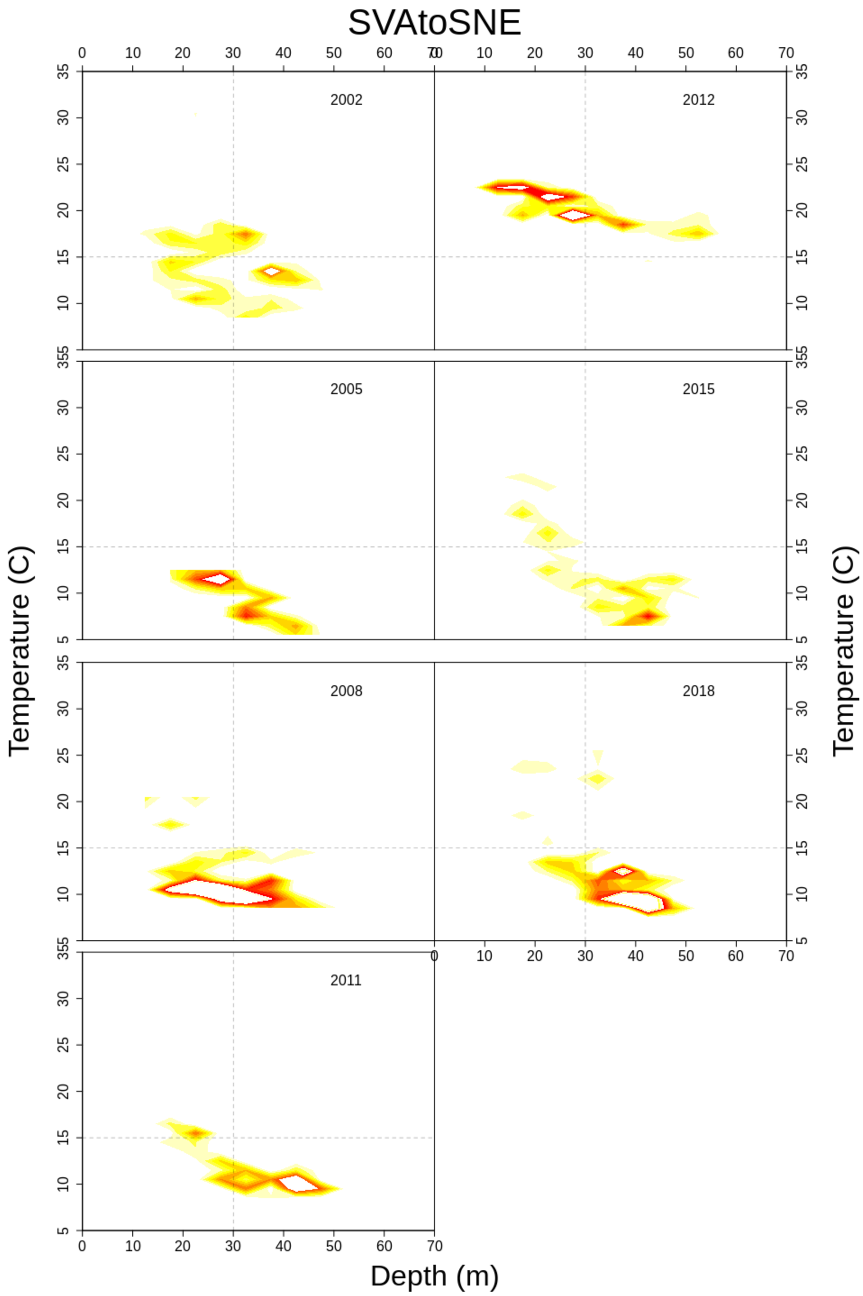



Figure 64: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in SVAtoSNE. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15°$ C and 30 m depth are for reference only.

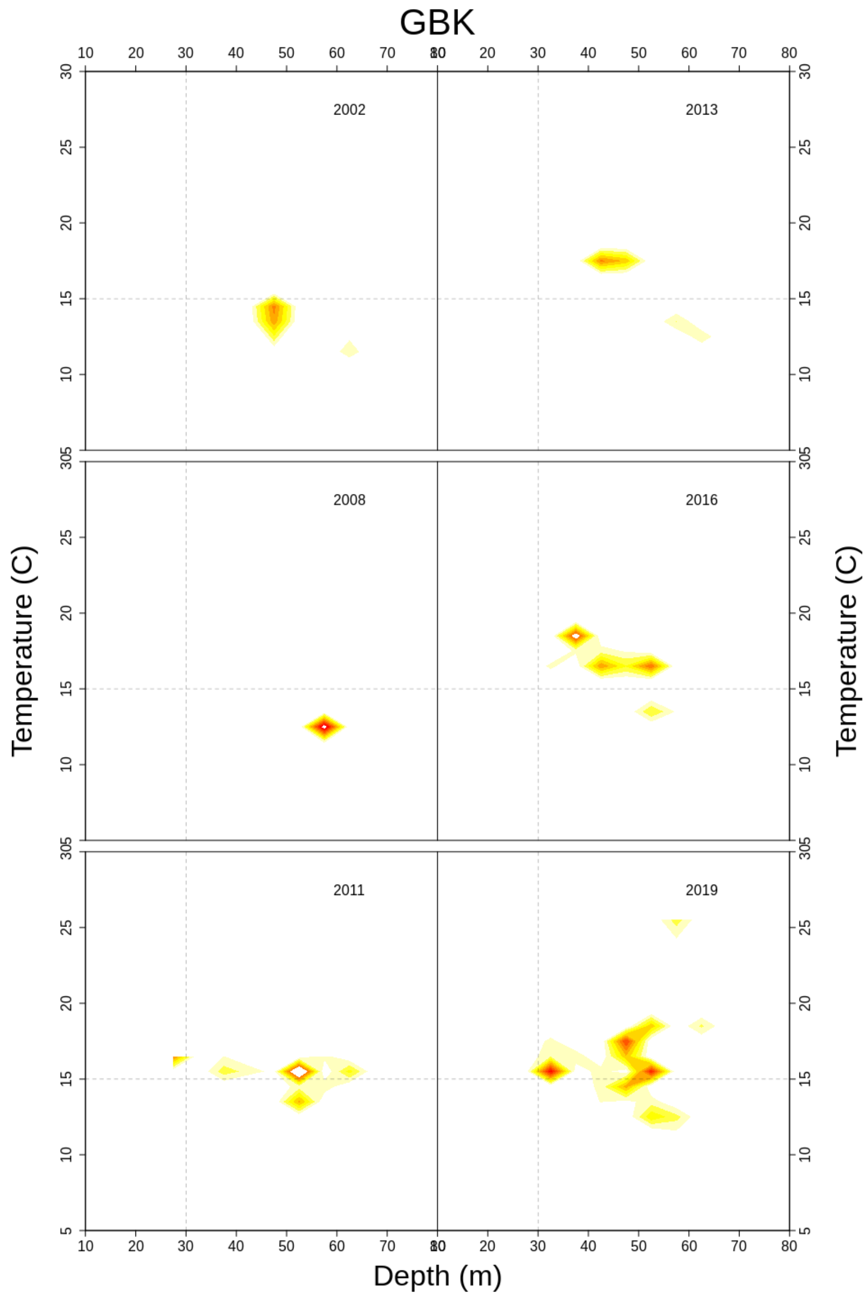



Figure 65: Total surfclams caught in the NEFSC clam survey at depth and temperature by year in GBK. Warmer colors in the contour represent larger catches. Catches are relative within each year and colors are not compareable across years. The dashed lines are drawn at $15^\circ$ C and 30 m depth are for reference only.

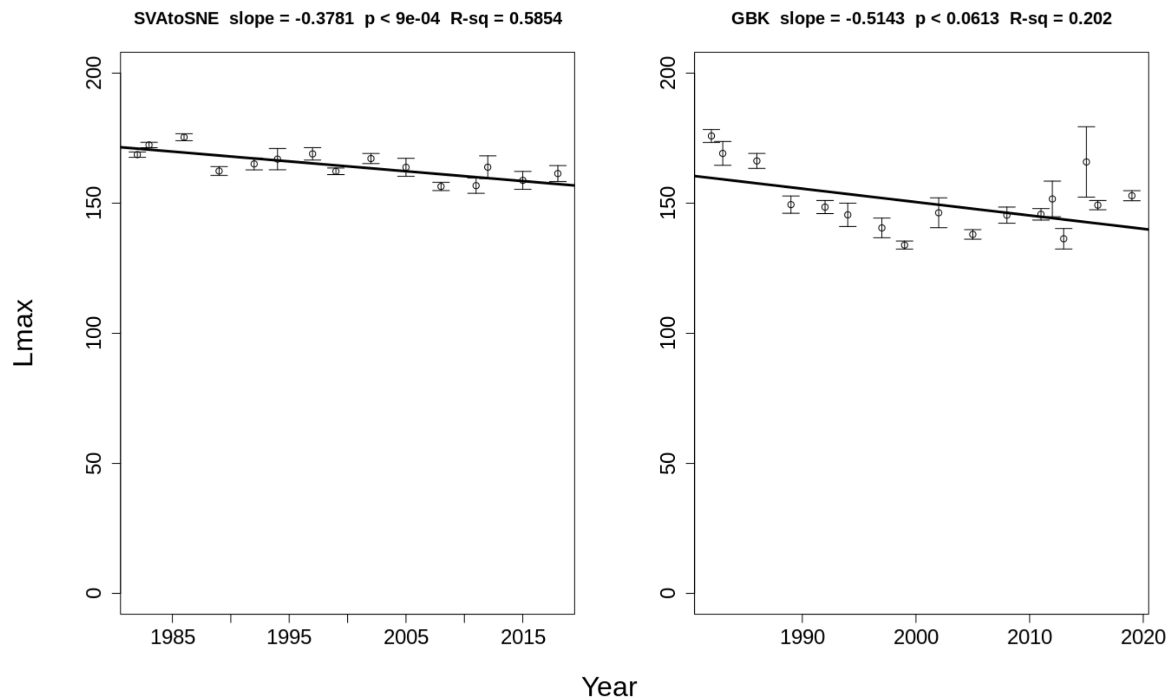



Figure 66: Estimated values of the parameter $L_\infty$ for Atlantic surfclam in NEFSC clam surveys, over time in each region. The $L_\infty$ values for each region were fit with an inverse variance weighted regression, and the slope, p-value and $R^2$ that result are shown above each plot.

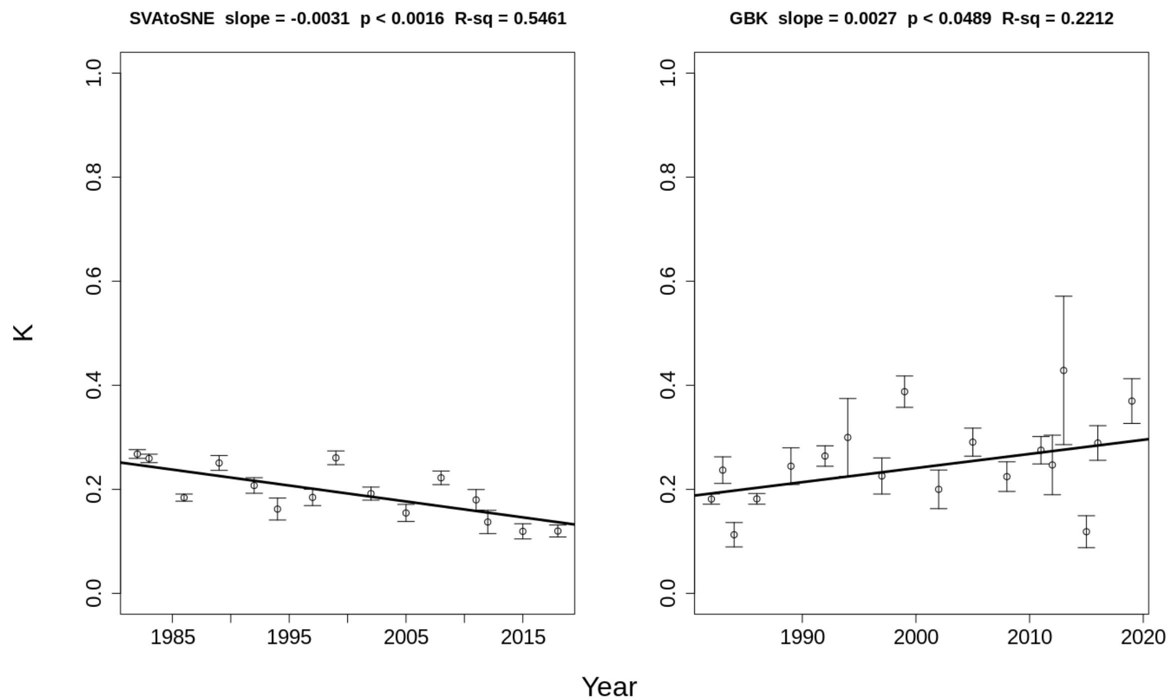



Figure 67: Estimated values of the parameter $K$ for Atlantic surfclam in NEFSC clam surveys, over time in each region. The $K$ values for each region were fit with an inverse variance weighted regression, and the slope, p-value and $R^2$ that result are shown above each plot.

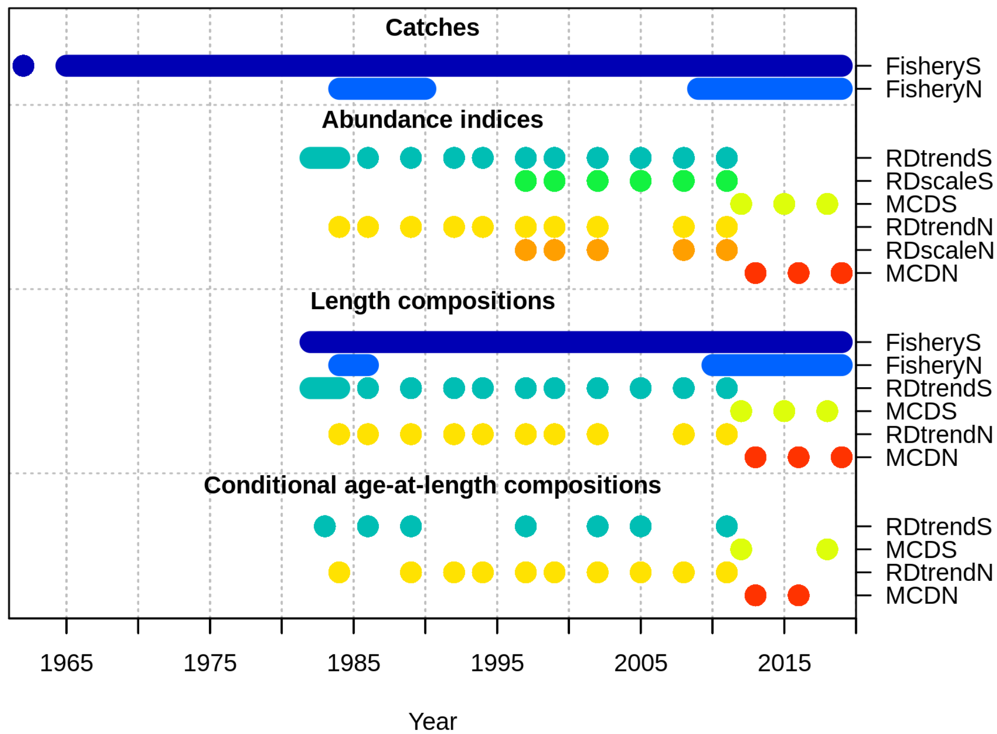



Figure 68: Data included in the Atlantic surfclam assessment model. RD scale was not included in the likelihood.

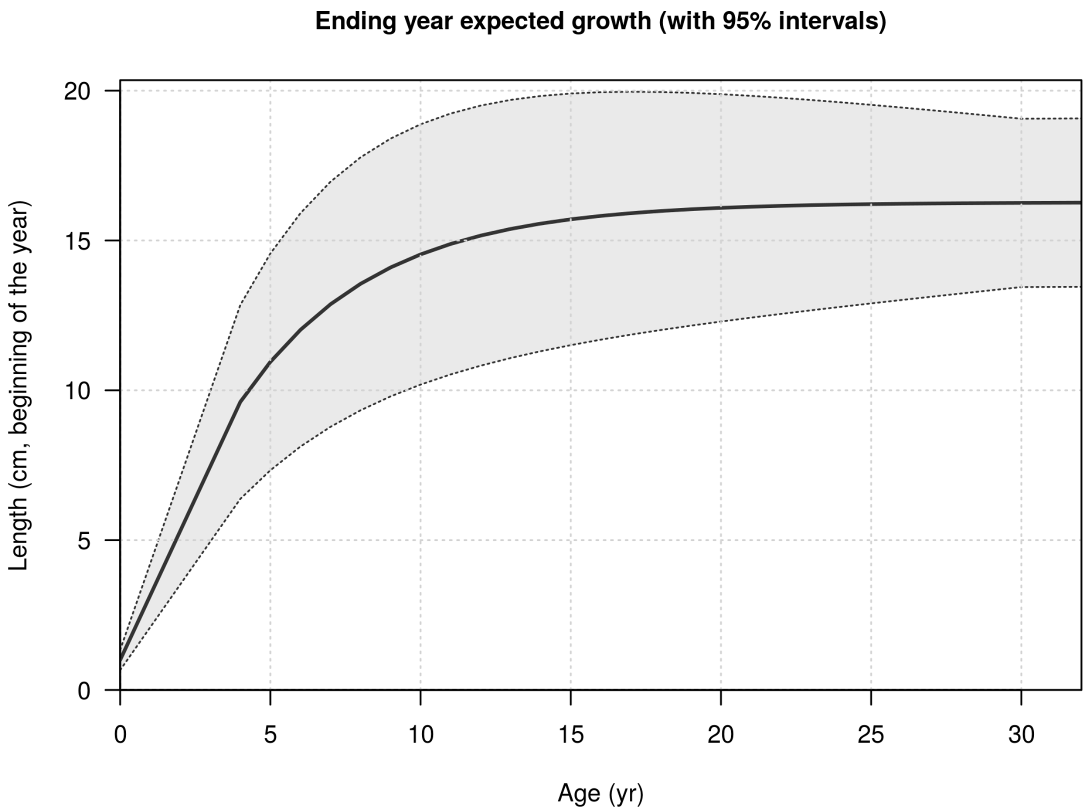



Figure 69: Length at age relationship from the previous Northeast Fisheries Science Center (2017a) assessment model for Atlantic surfclam.

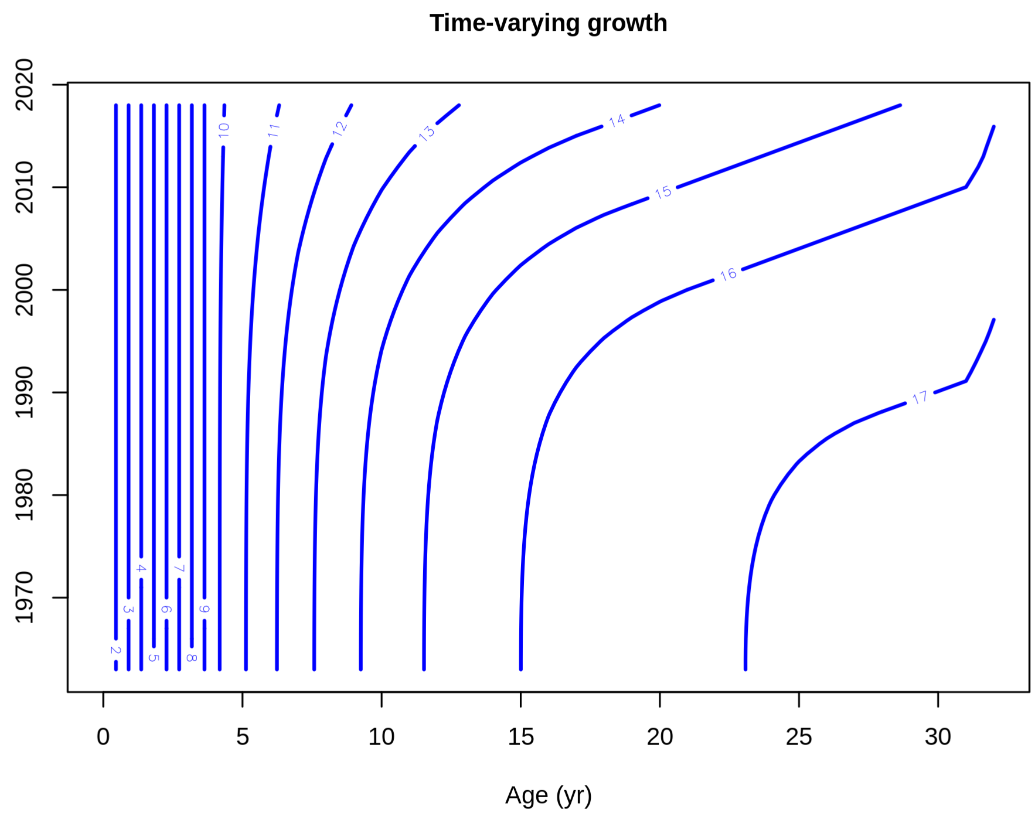



Figure 70: Time varying growth estimated in the assessment model for Atlantic surfclam.

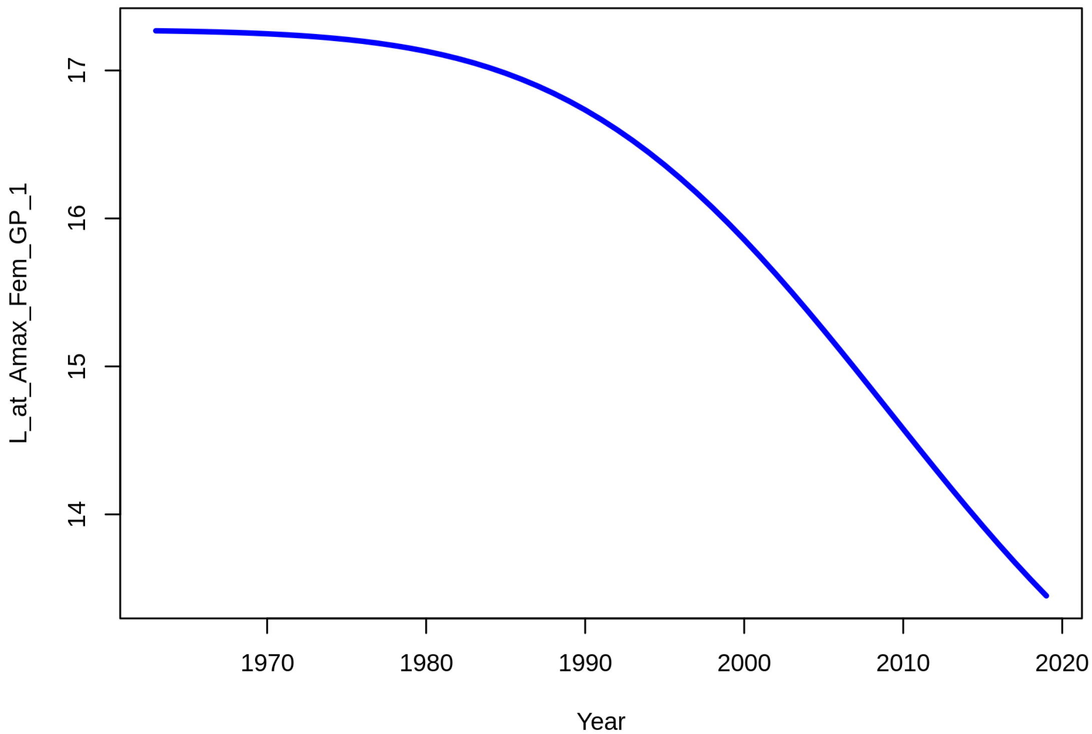



Figure 71: Trend in $L_\infty$ estimated in the assessment model for Atlantic surfclam.

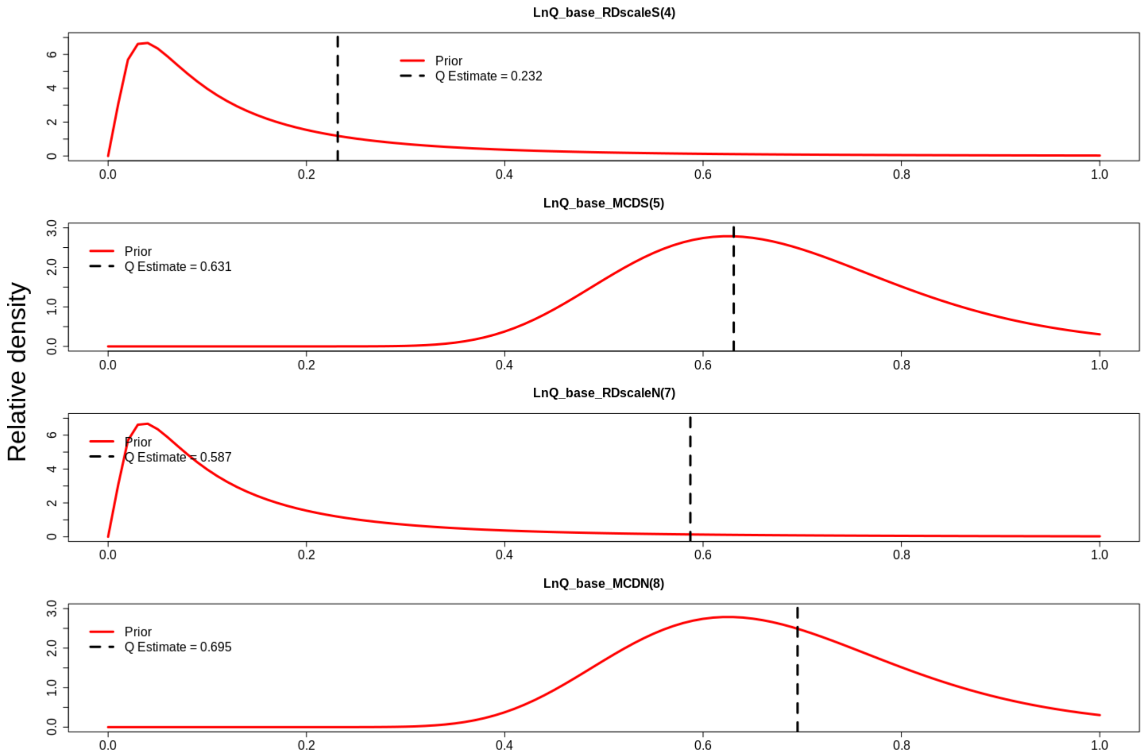



Figure 72: Estimated catchability parameters for each survey fleet and their prior distributions.

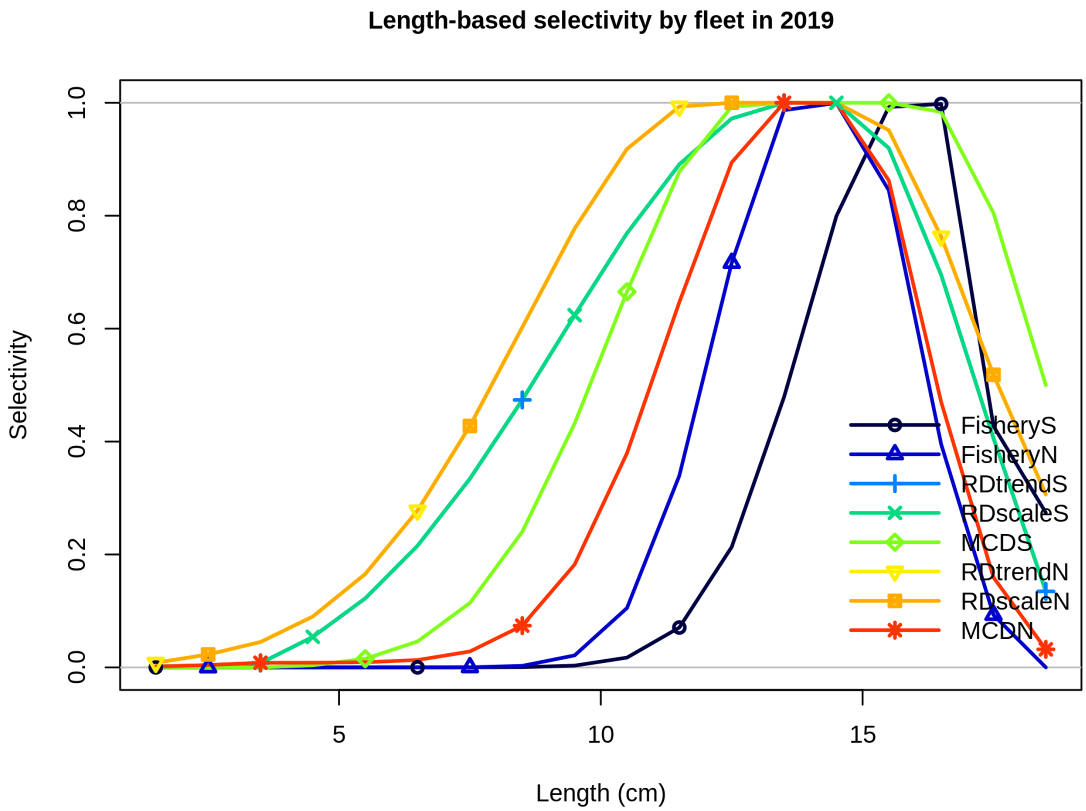



Figure 73: Comparison of selectivity curves for each fleet included in the assessment model for Atlantic surfclam. RD trend and RD scale have identical selectivities because they are from the same survey (RD scale was not included in the likelihood).

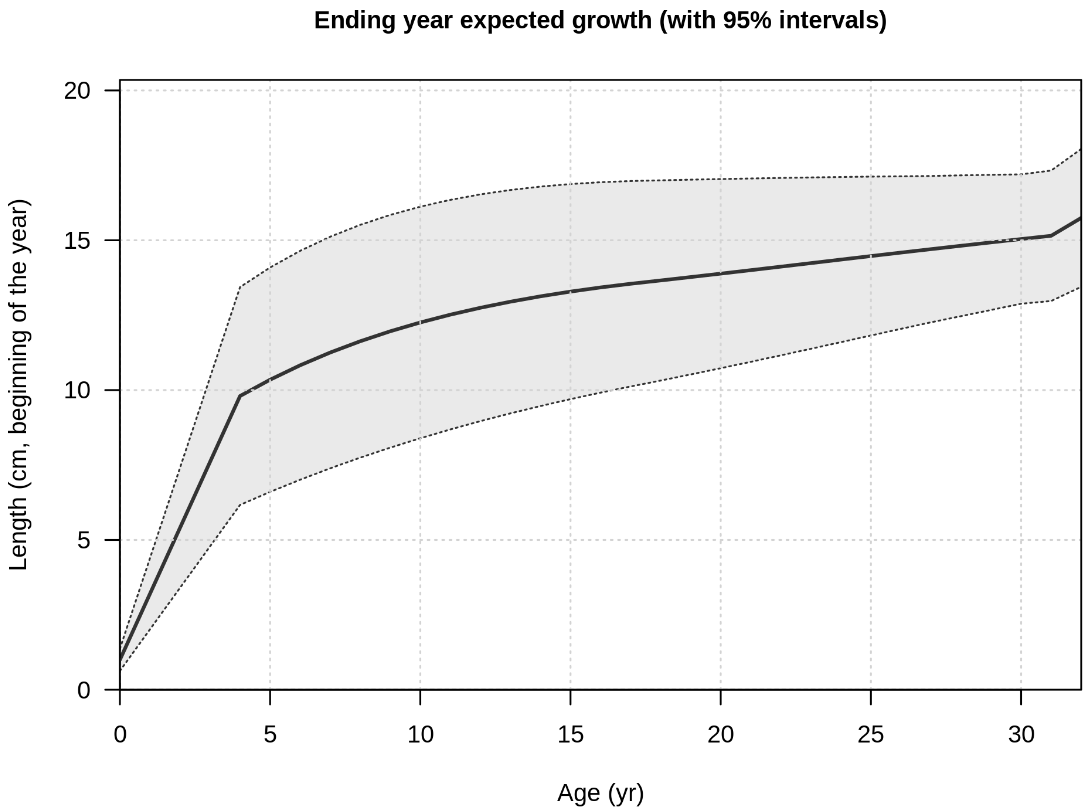



Figure 74: Length at age relationship from the assessment model for Atlantic surfclam.

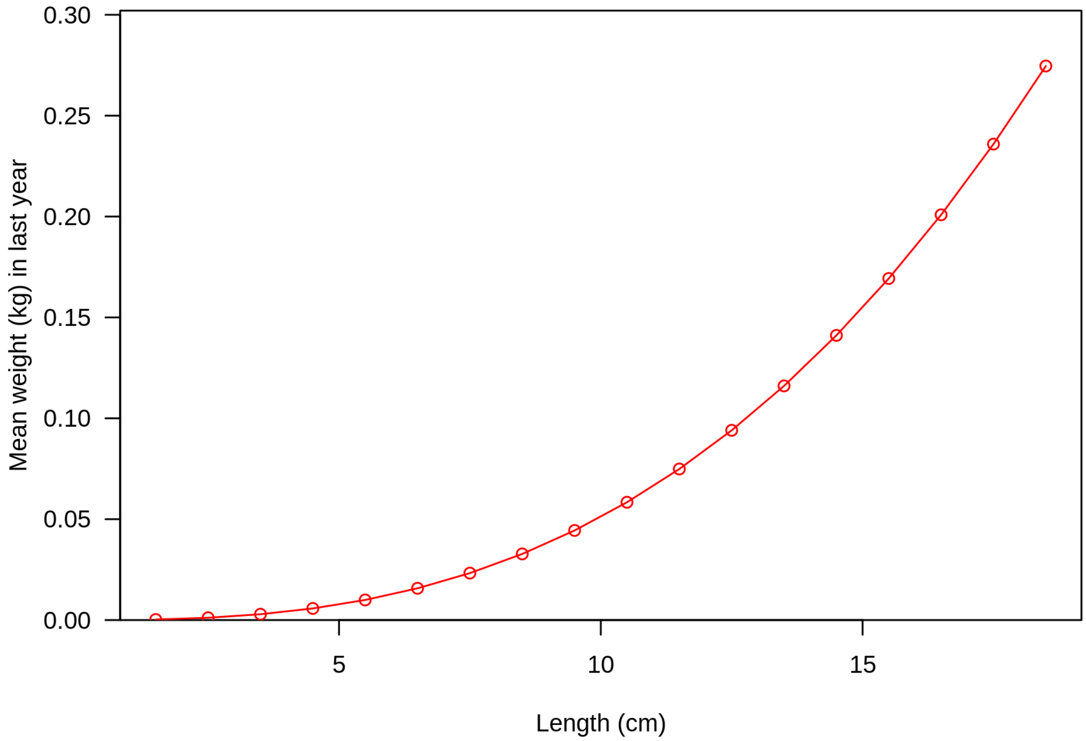



Figure 75: Weight at length relationship used in the assessment model for Atlantic surfclam.

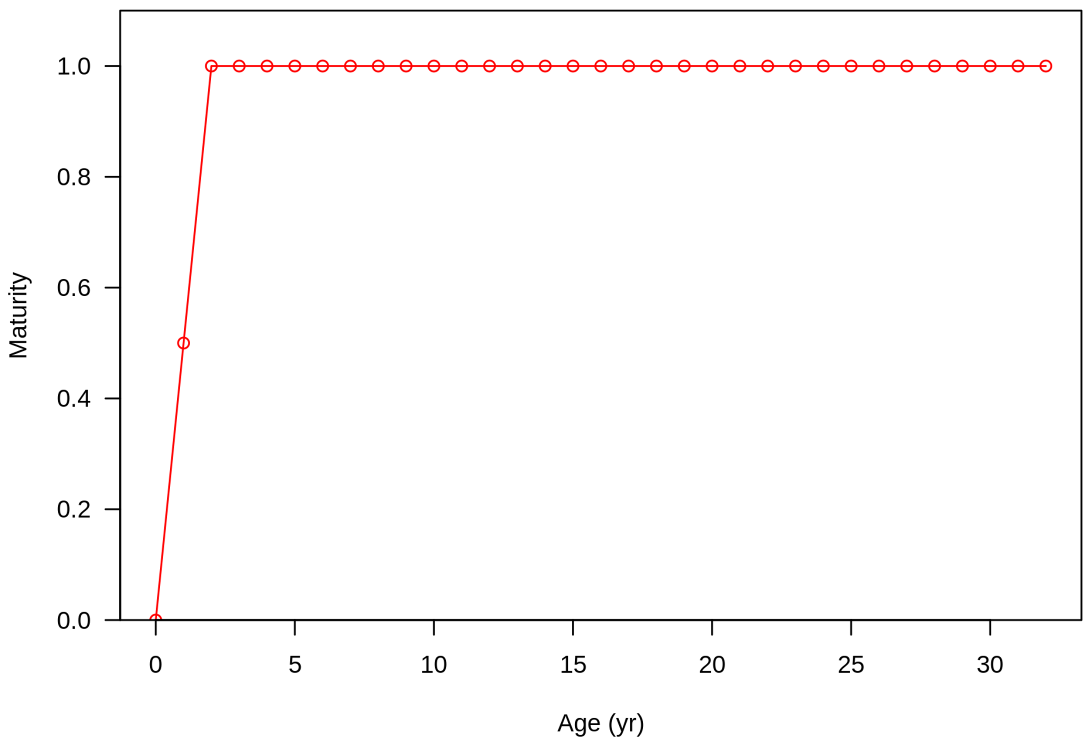



Figure 76: Maturity at age relationship used in the assessment model for Atlantic surfclam.

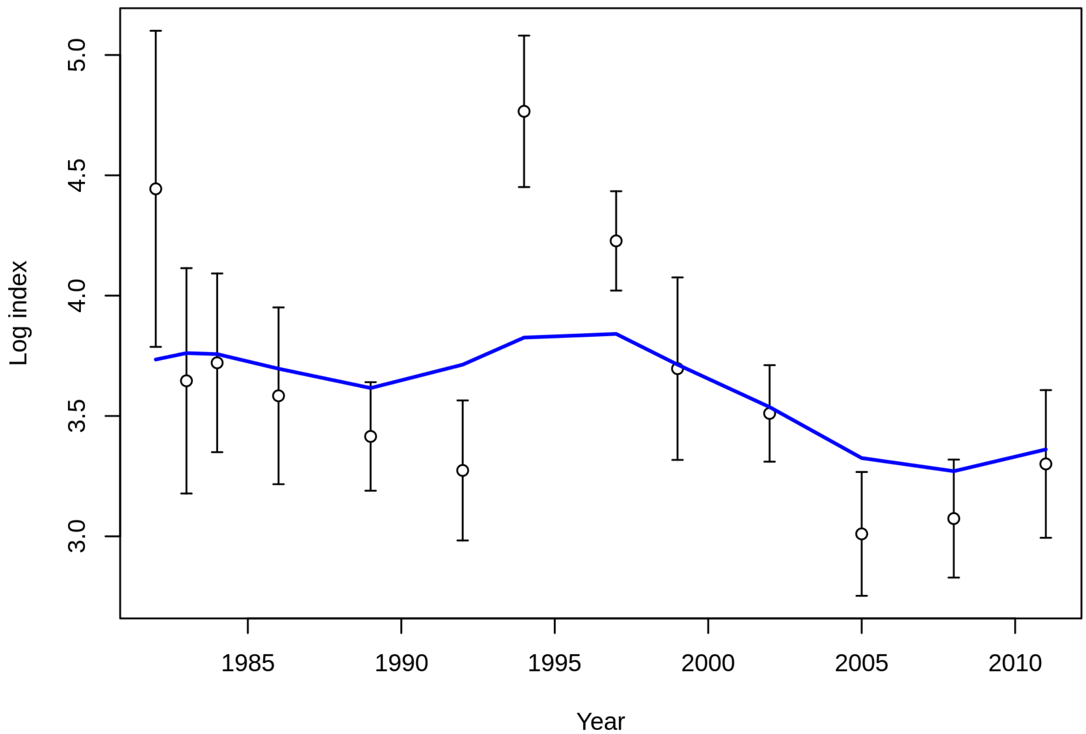



Figure 77: Fit to log index data on log scale for RDtrendS (southern area) survey for Atlantic surfclam. Vertical lines are 95% confidence intervals.

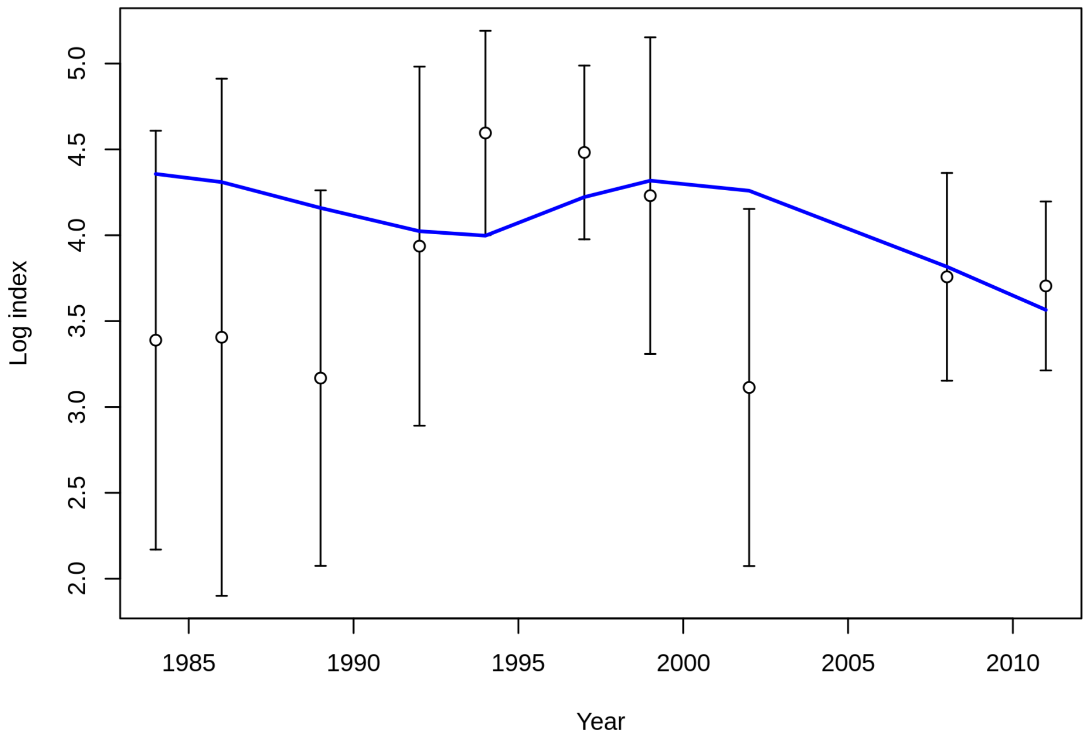



Figure 78: Fit to log index data on log scale for RDtrendN (northern area) survey for Atlantic surfclam. Vertical lines are 95% confidence intervals.

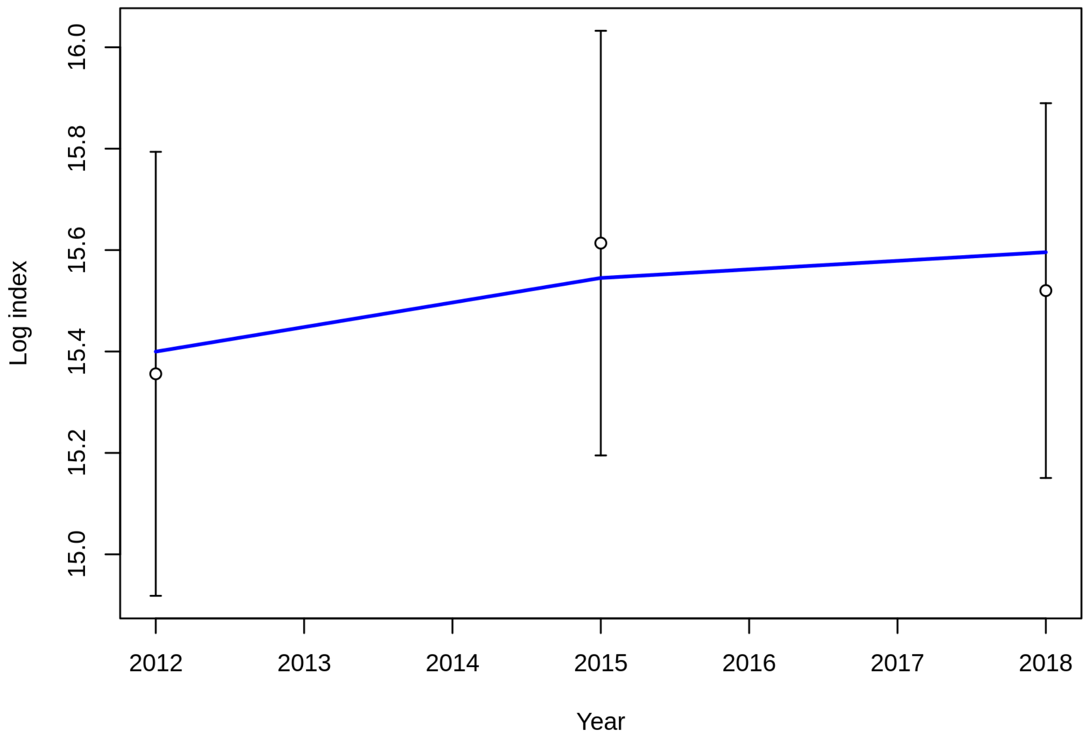



Figure 79: Fit to log index data on log scale for MCDS (southern area) survey for Atlantic surfclam. Vertical lines are 95% confidence intervals.

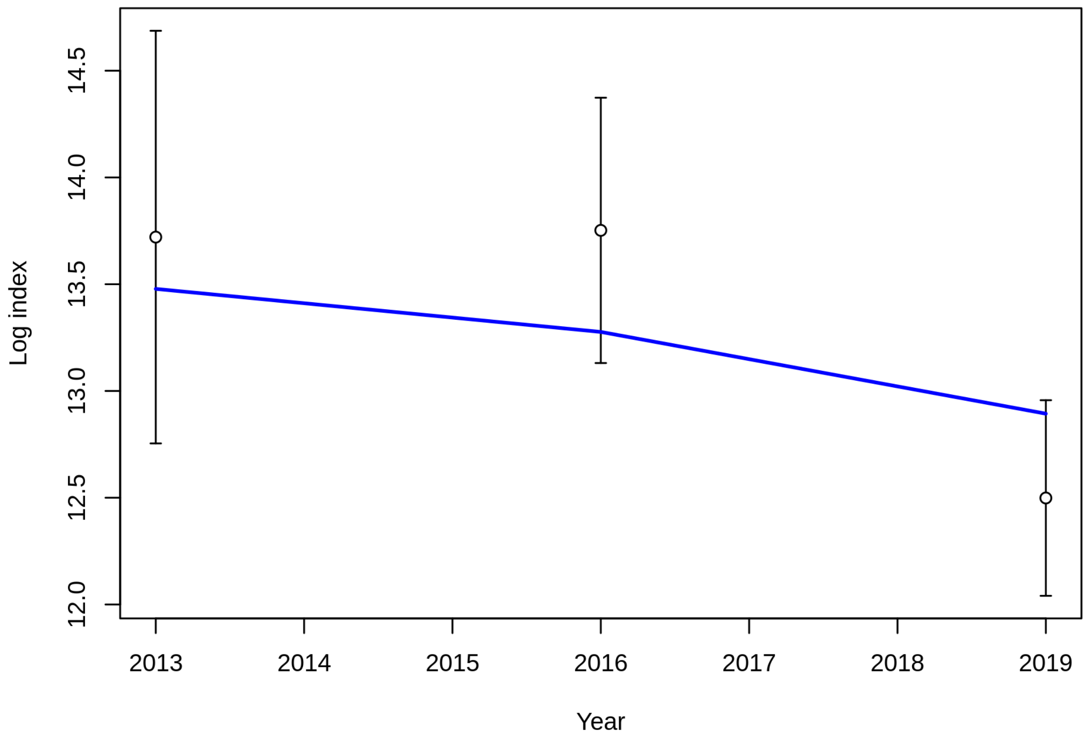



Figure 80: Fit to log index data on log scale for MCDN (northern area) survey for Atlantic surfclam. Vertical lines are 95% confidence intervals.

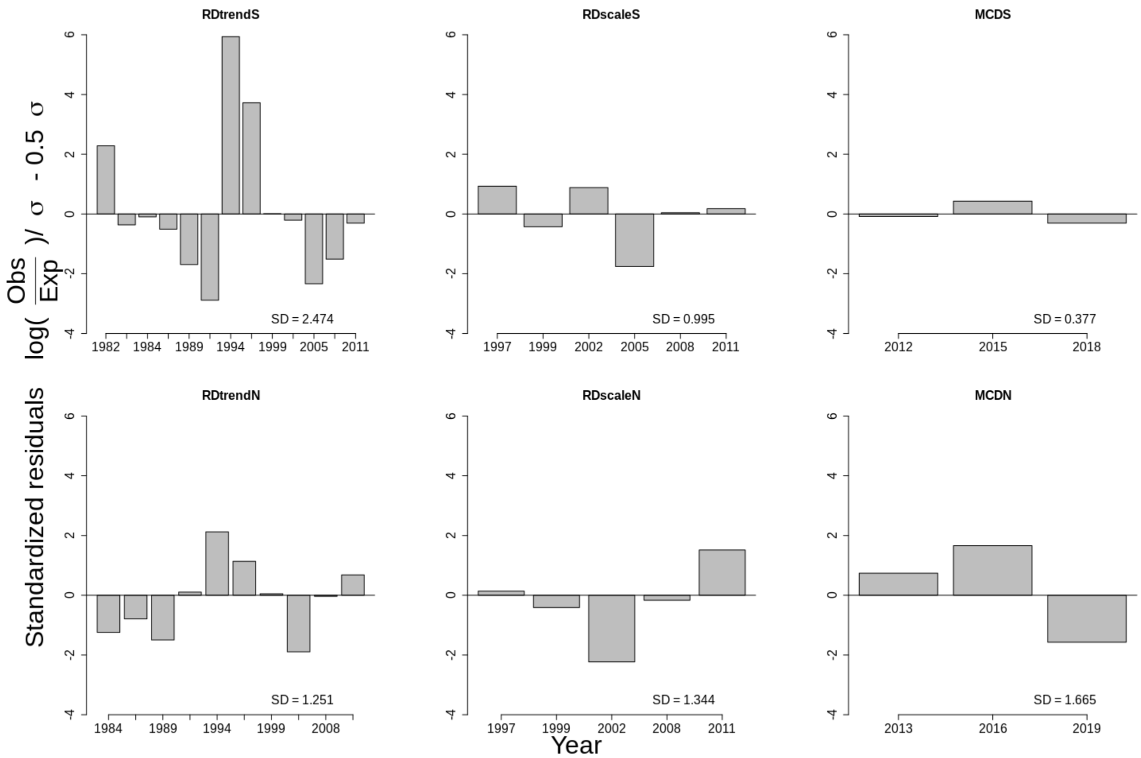



Figure 81: Residuals from the model fits to each survey index used in the assessment model for Atlantic surfclam by year. The standard deviation of the residuals over the time series is indicated above the horizontal axis.

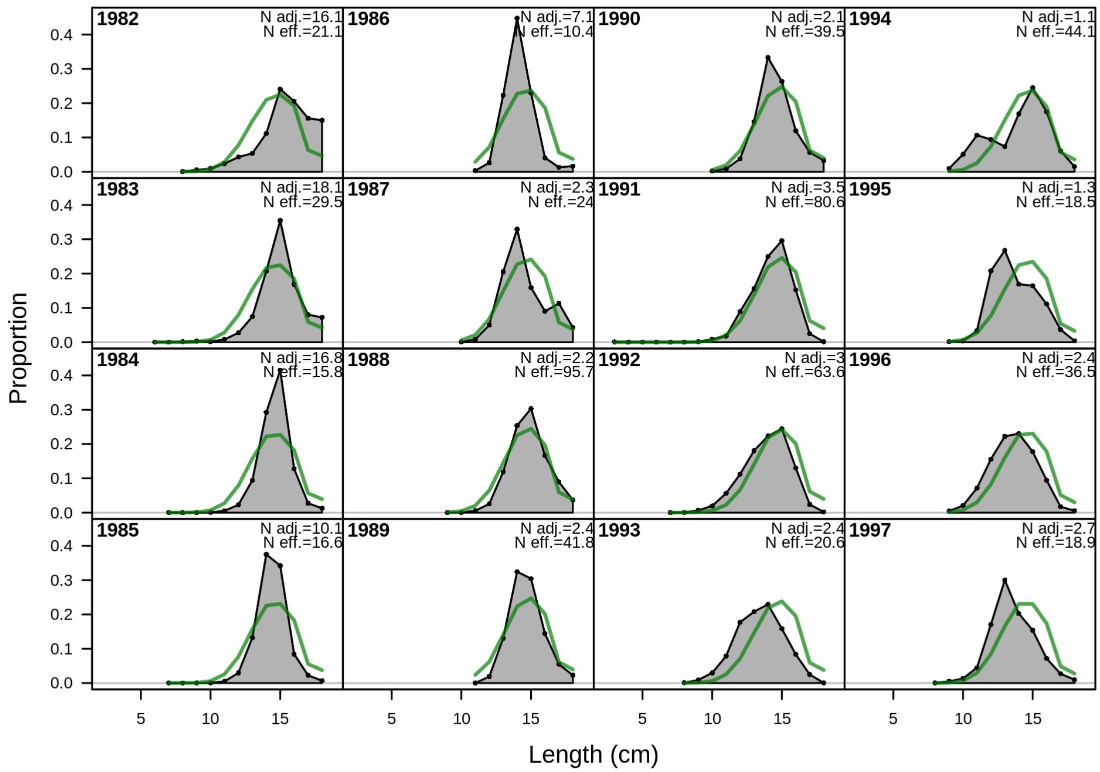



Figure 82: Model fit to length composition data from the commercial fishery in the southern area used in the assessment model for Atlantic surfclam.

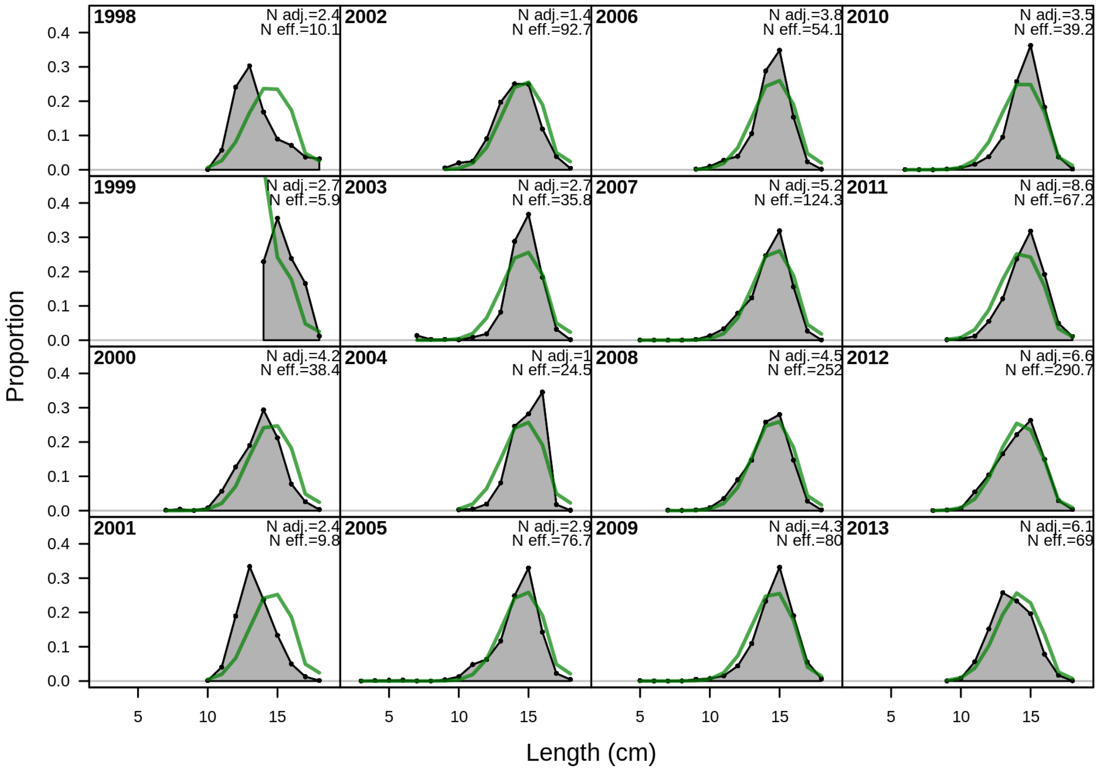



Figure 82 cont.

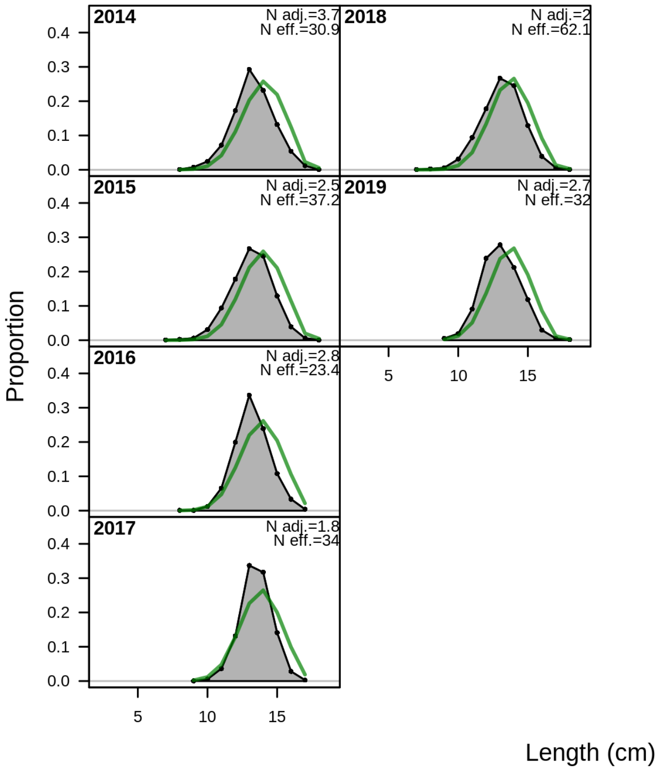



Figure 82 cont.

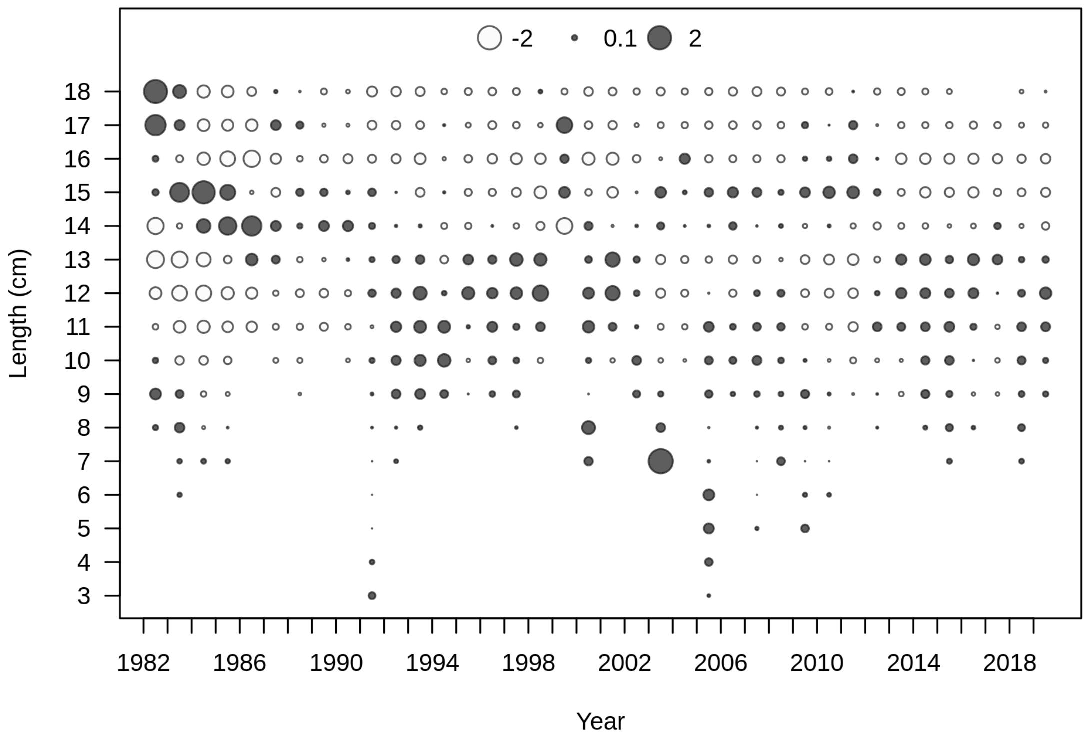



Figure 83: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

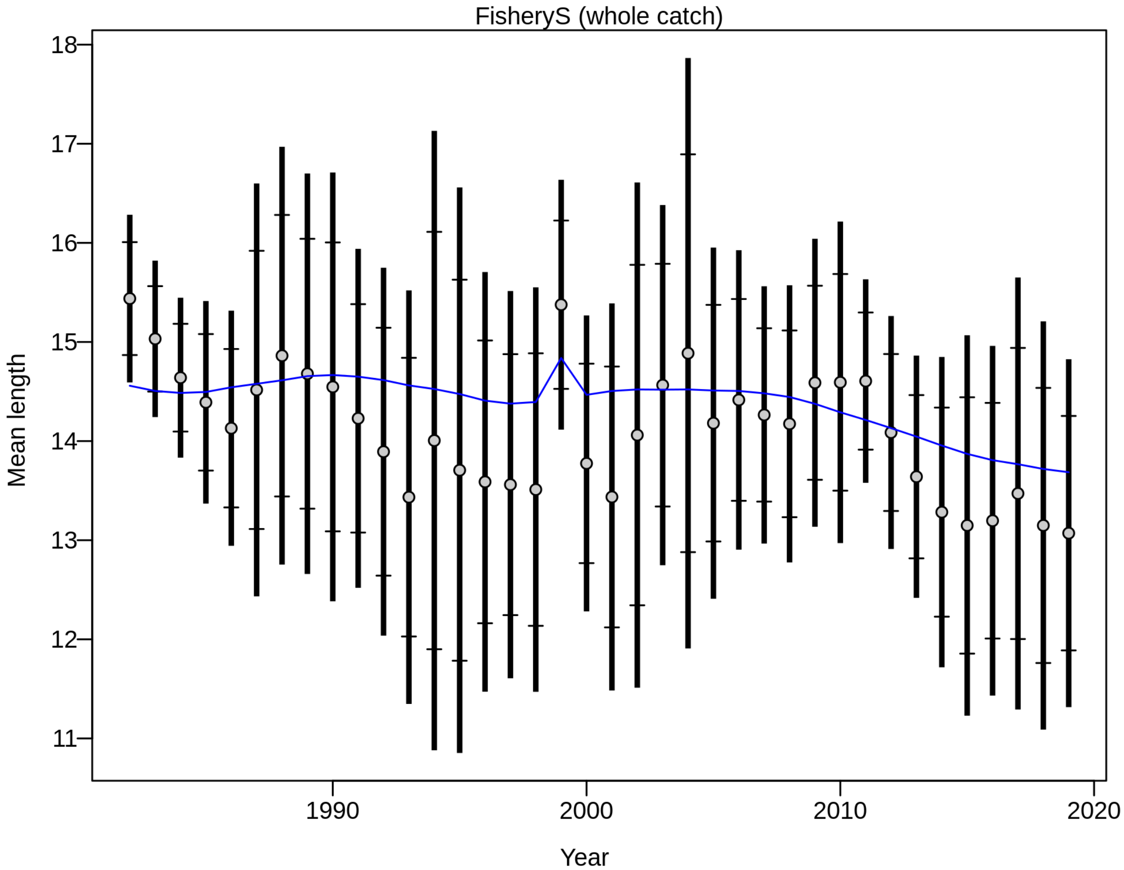



Figure 84: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data for the southern area used in the assessment model for Atlantic surfclam.

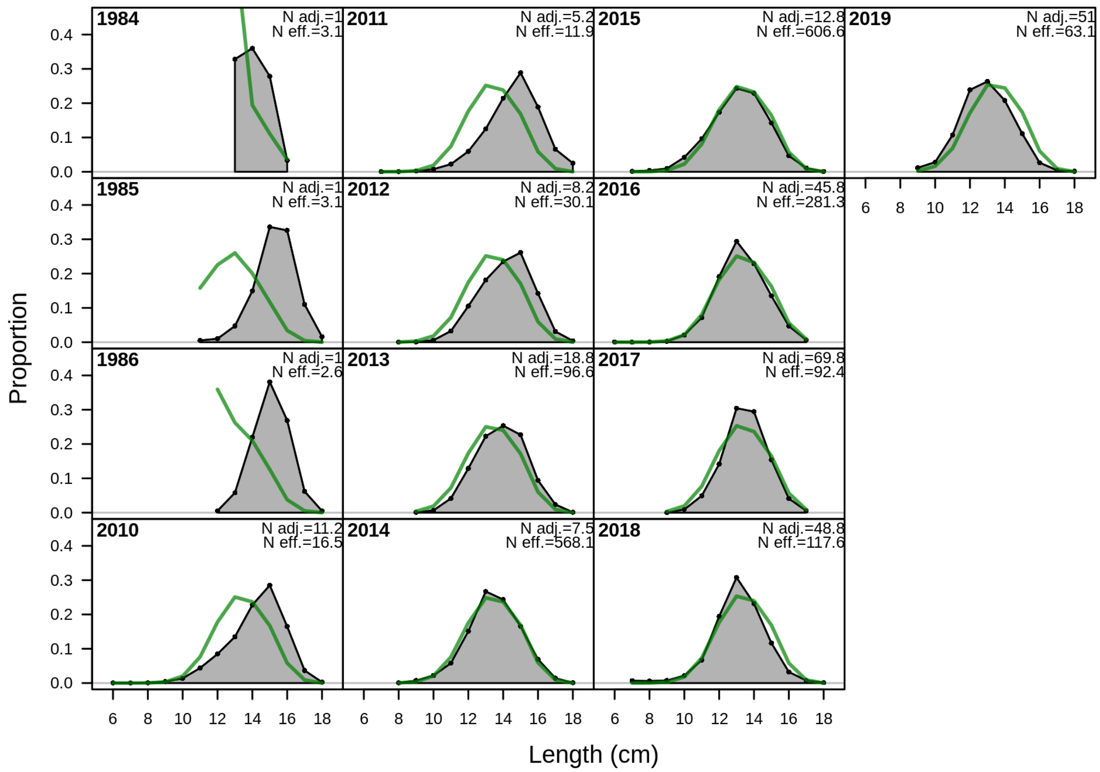



Figure 85: Model fit to length composition data from the commercial fishery in the northern area used in the assessment model for Atlantic surfclam.

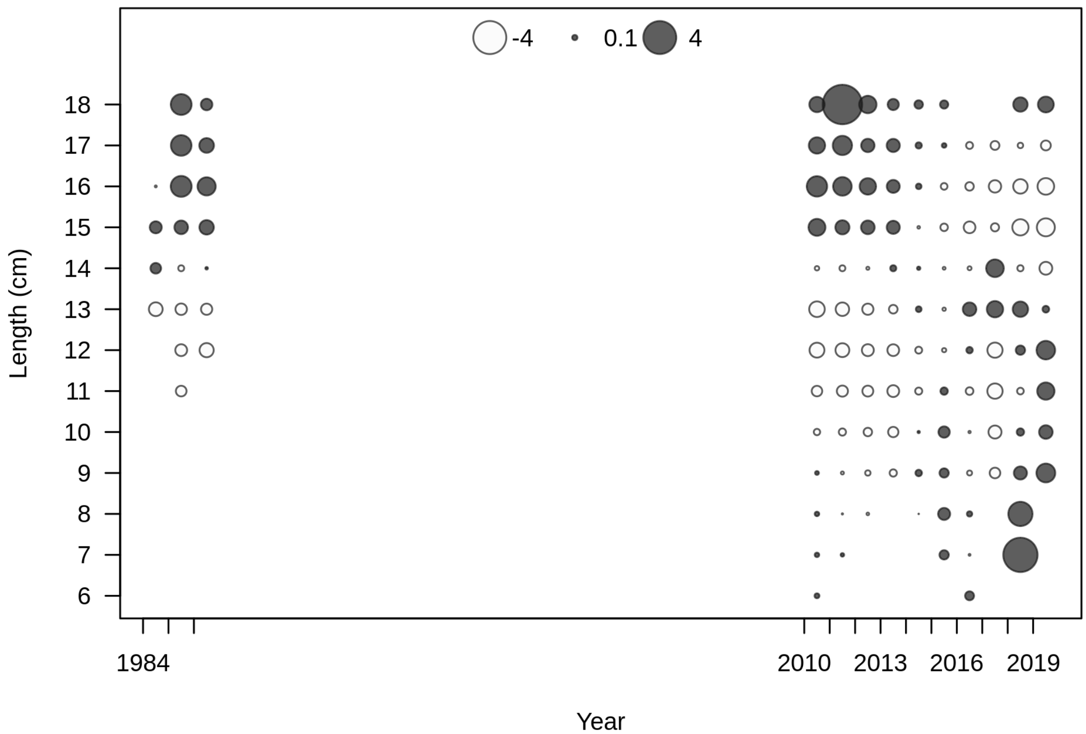



Figure 86: Pearson residuals from the fit to commercial length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

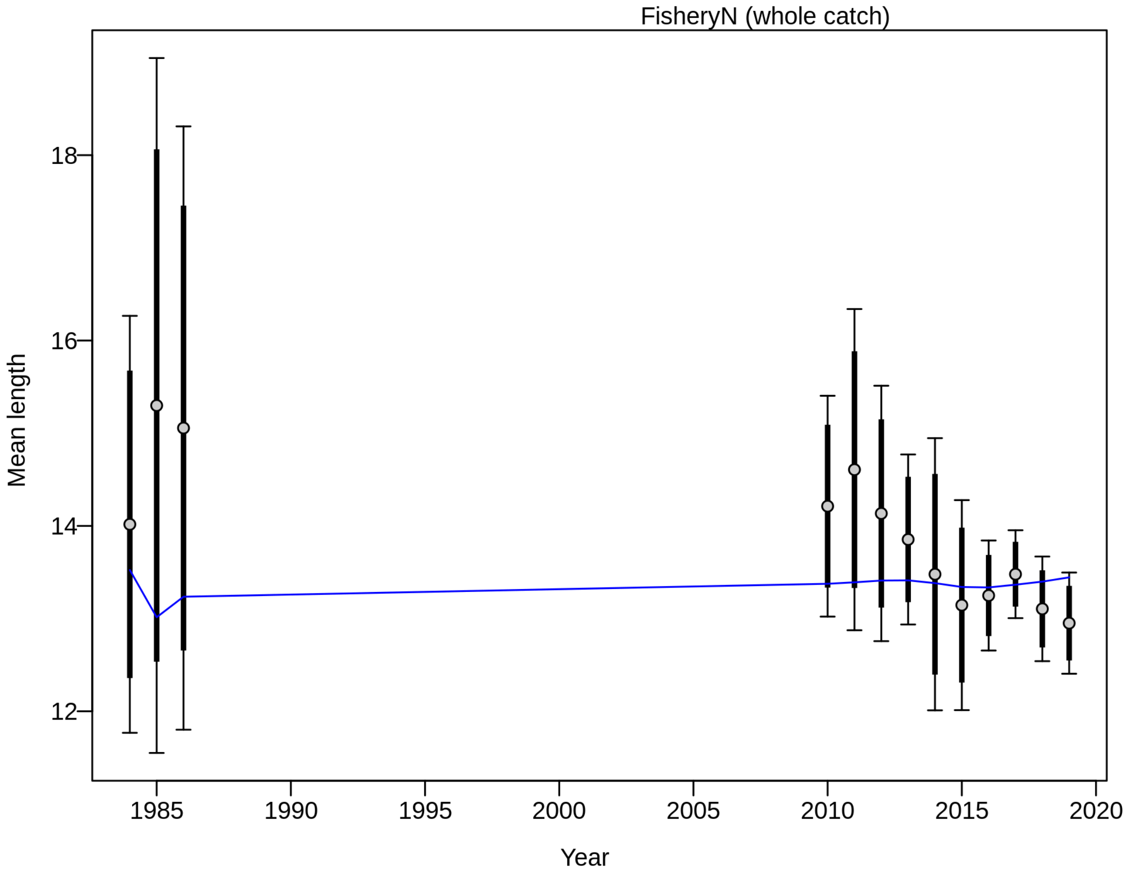



Figure 87: Observed mean length vs. the mean length predicted by the model based on fits to commercial length composition data for the northern area used in the assessment model for Atlantic surfclam.

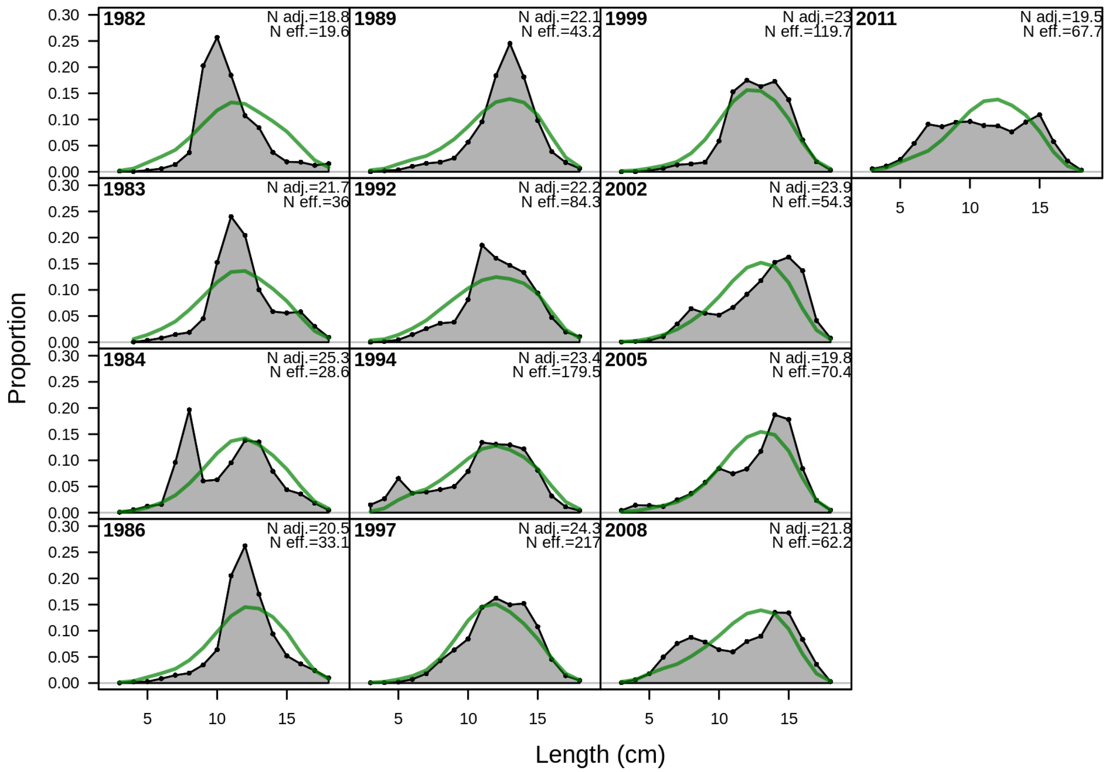



Figure 88: Model fit to length composition data from the NEFSC survey (RDtrendS) used in the assessment model for Atlantic surfclam.

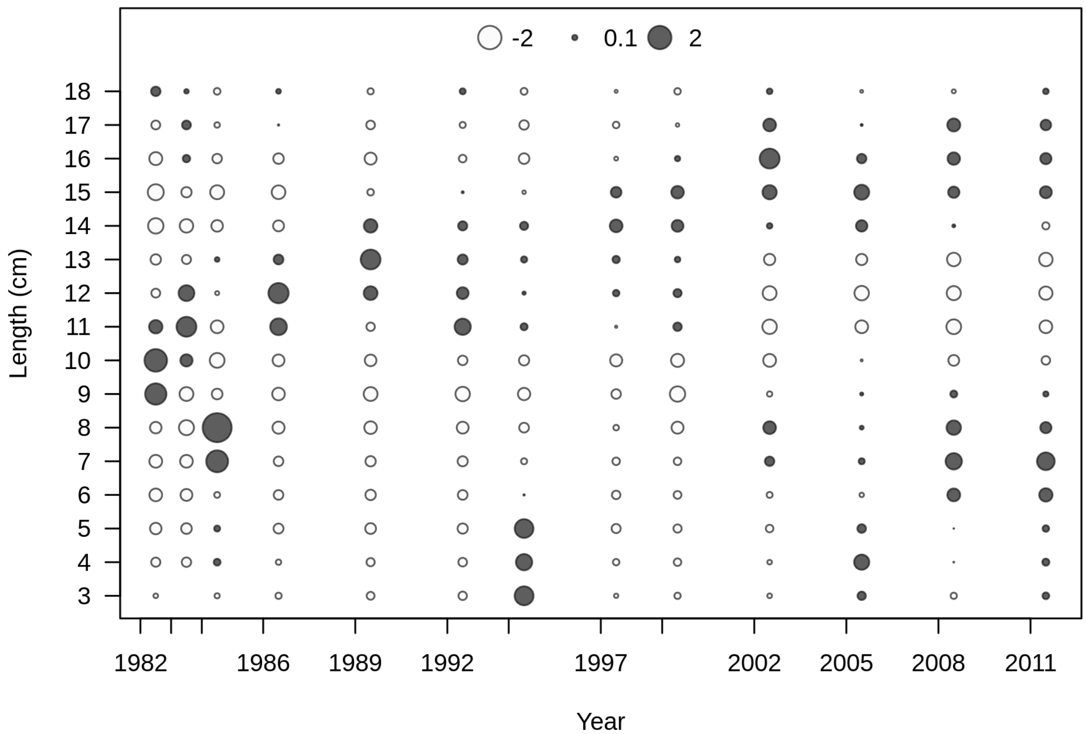



Figure 89: Pearson residuals from the fit to NEFSC survey (RDtrendS) length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

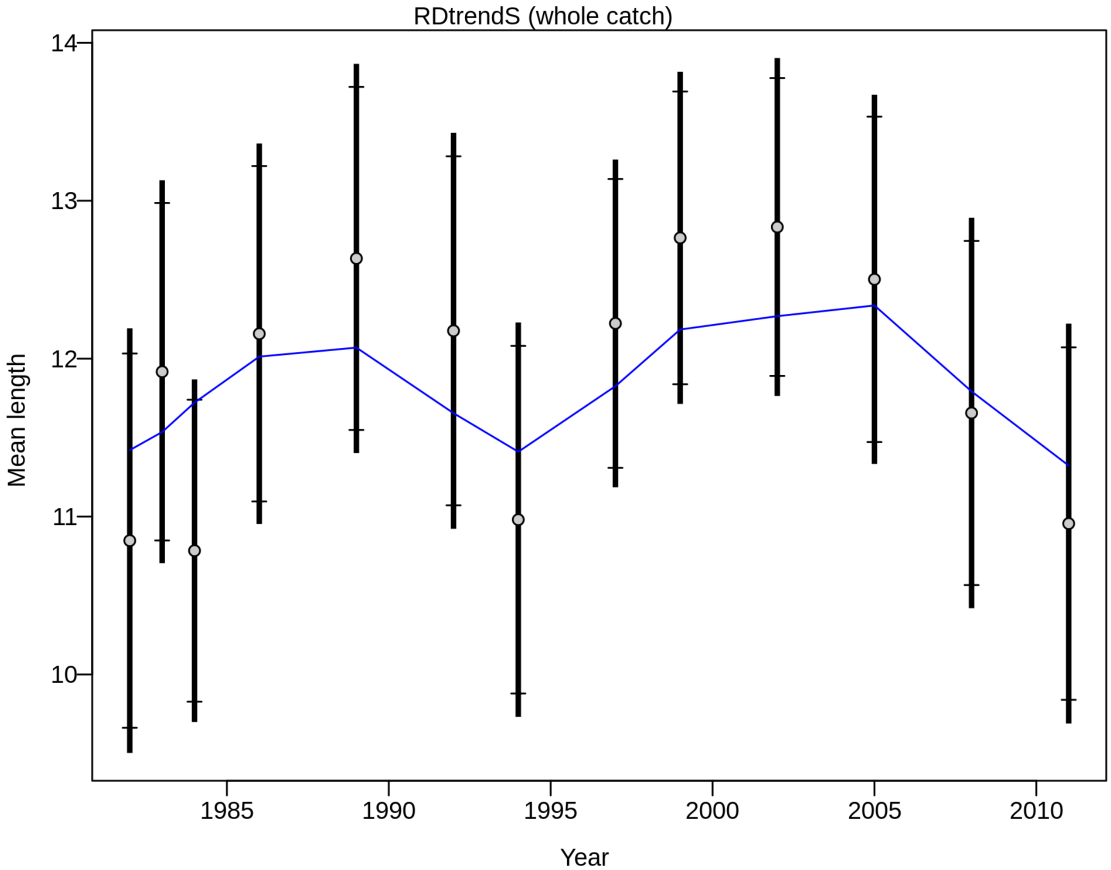



Figure 90: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RDtrendS) length composition data used in the assessment model for Atlantic surfclam.

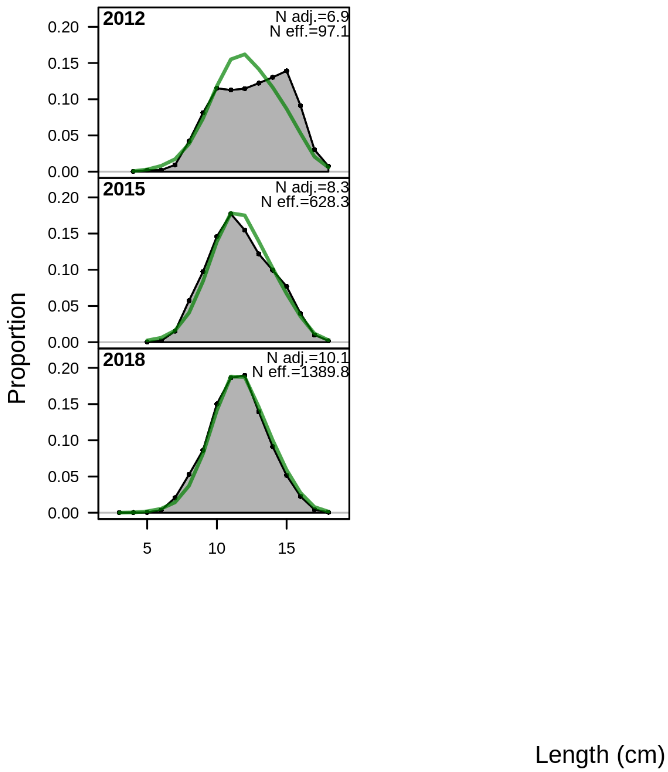



Figure 91: Model fit to length composition data from the NEFSC survey (RDtrendN) used in the assessment model for Atlantic surfclam.

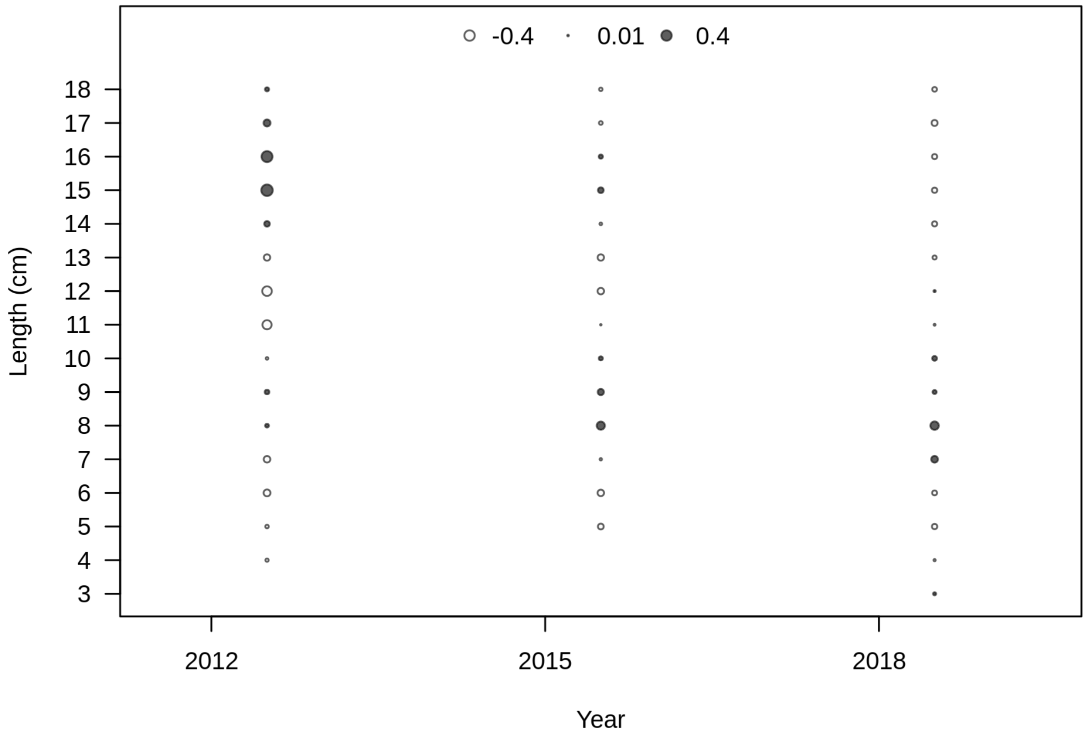



Figure 92: Pearson residuals from the fit to NEFSC survey (RDtrendN) length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

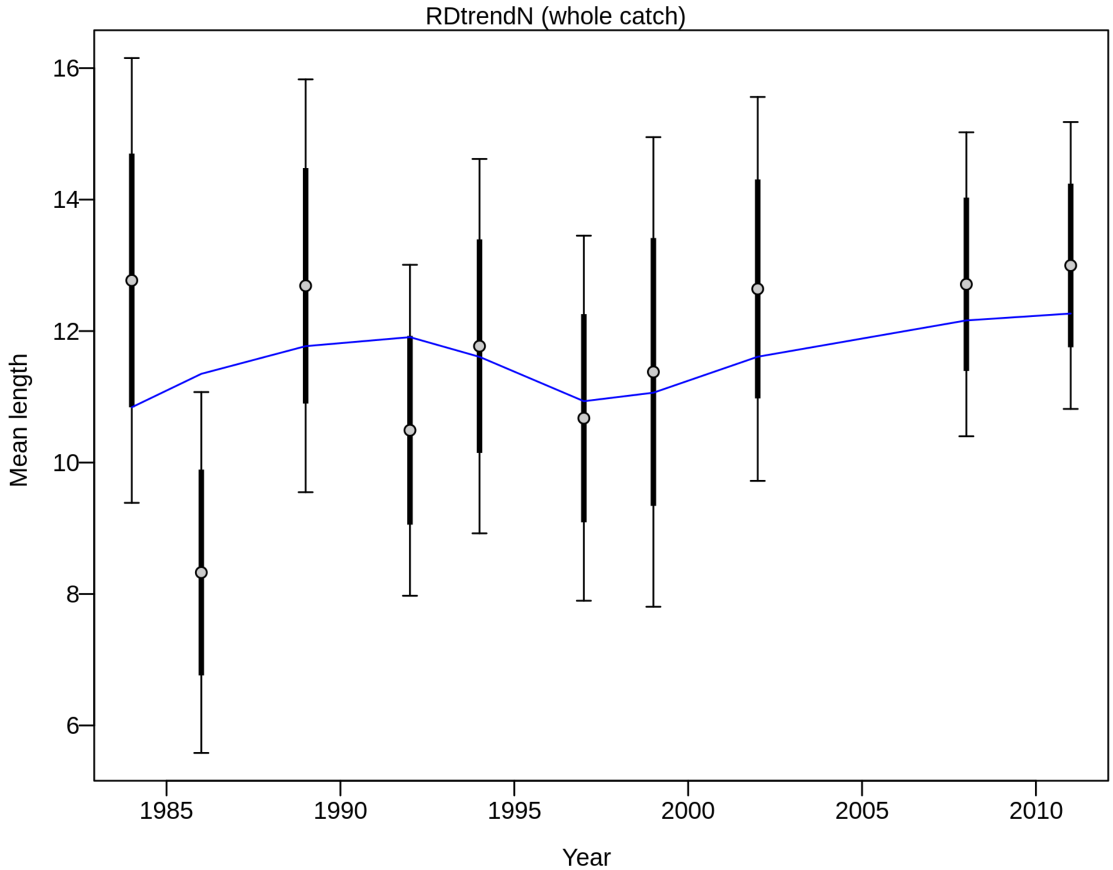



Figure 93: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (RDtrendN) length composition data used in the assessment model for Atlantic surfclam.

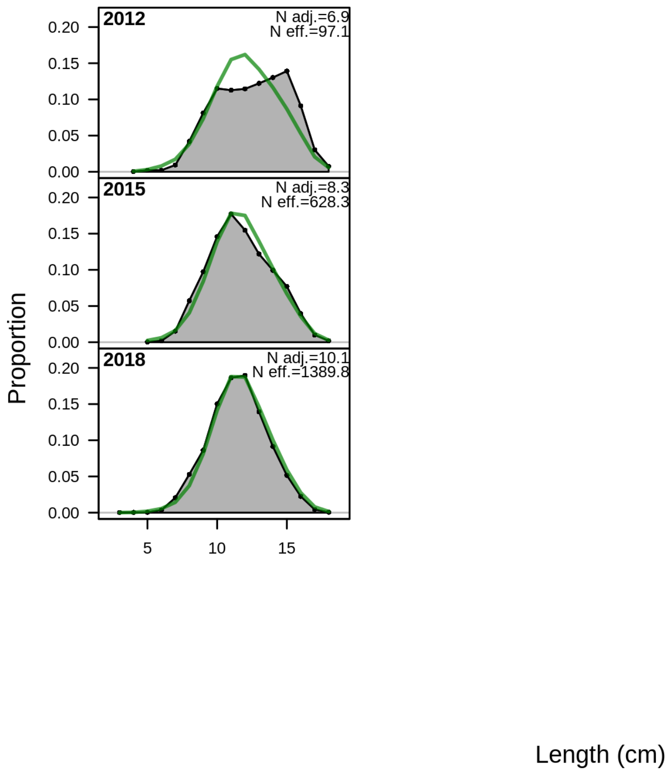



Figure 94: Model fit to length composition data from the NEFSC survey (MCDS) used in the assessment model for Atlantic surfclam.

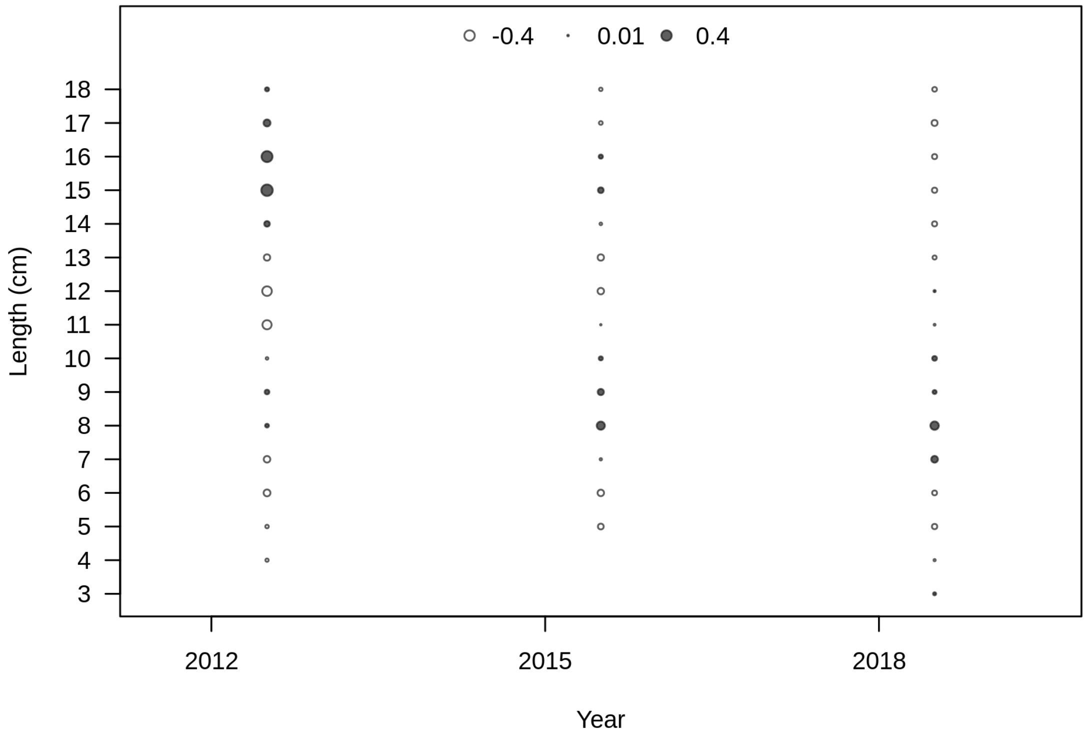



Figure 95: Pearson residuals from the fit to NEFSC survey (MCDS) length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

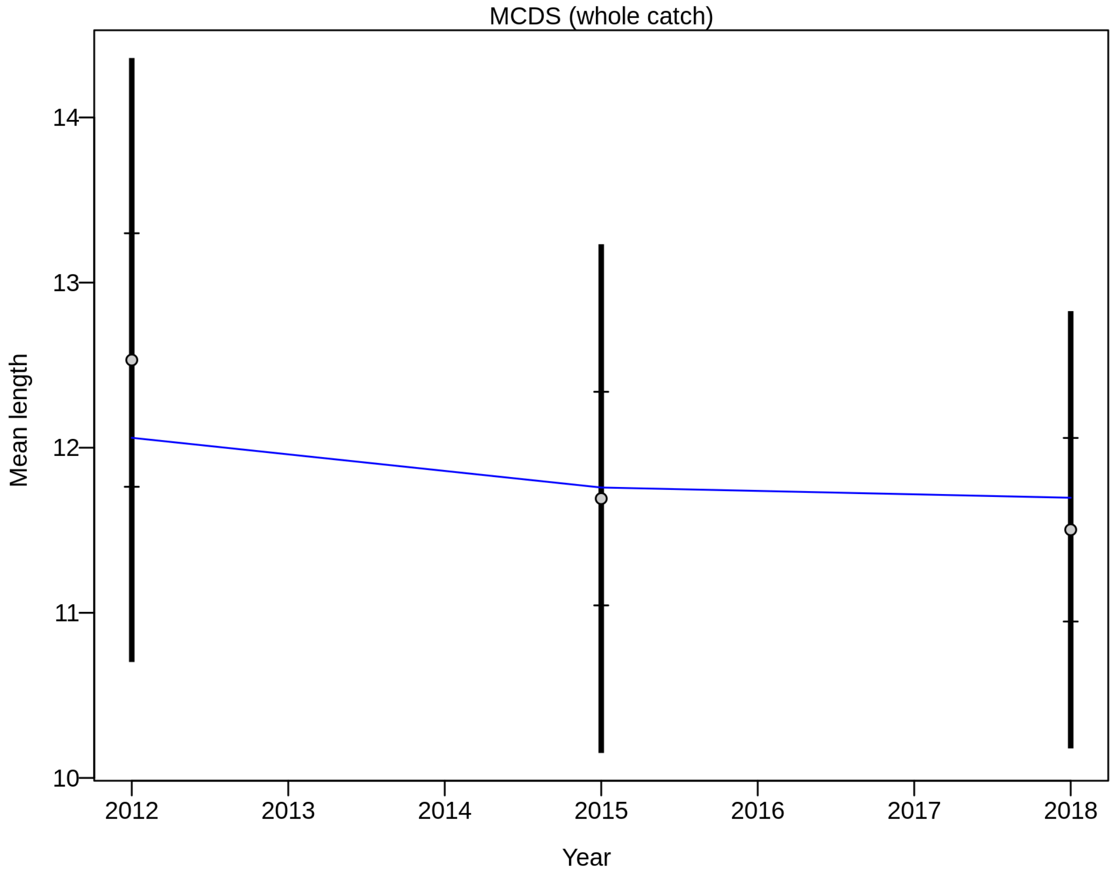



Figure 96: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (MCDS) length composition data used in the assessment model for Atlantic surfclam.

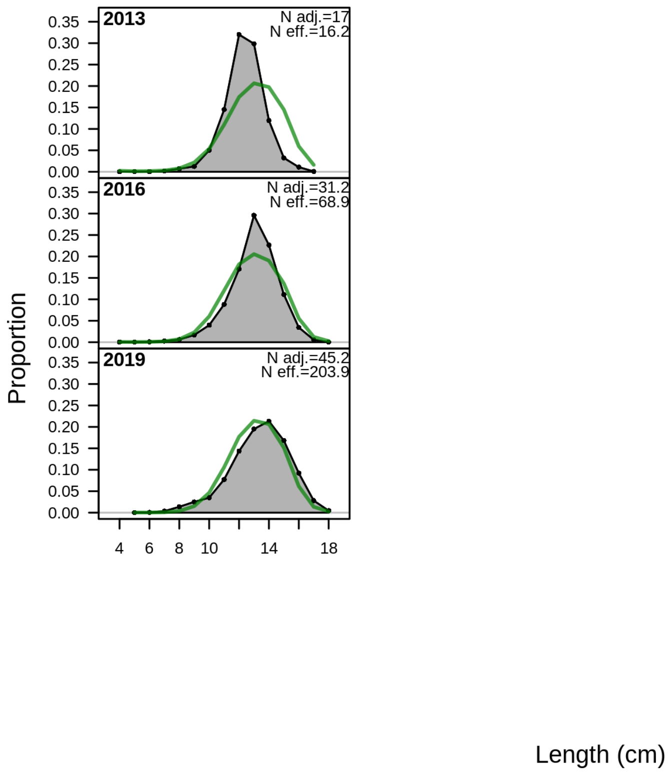



Figure 97: Model fit to length composition data from the NEFSC survey (MCDN) used in the assessment model for Atlantic surfclam.

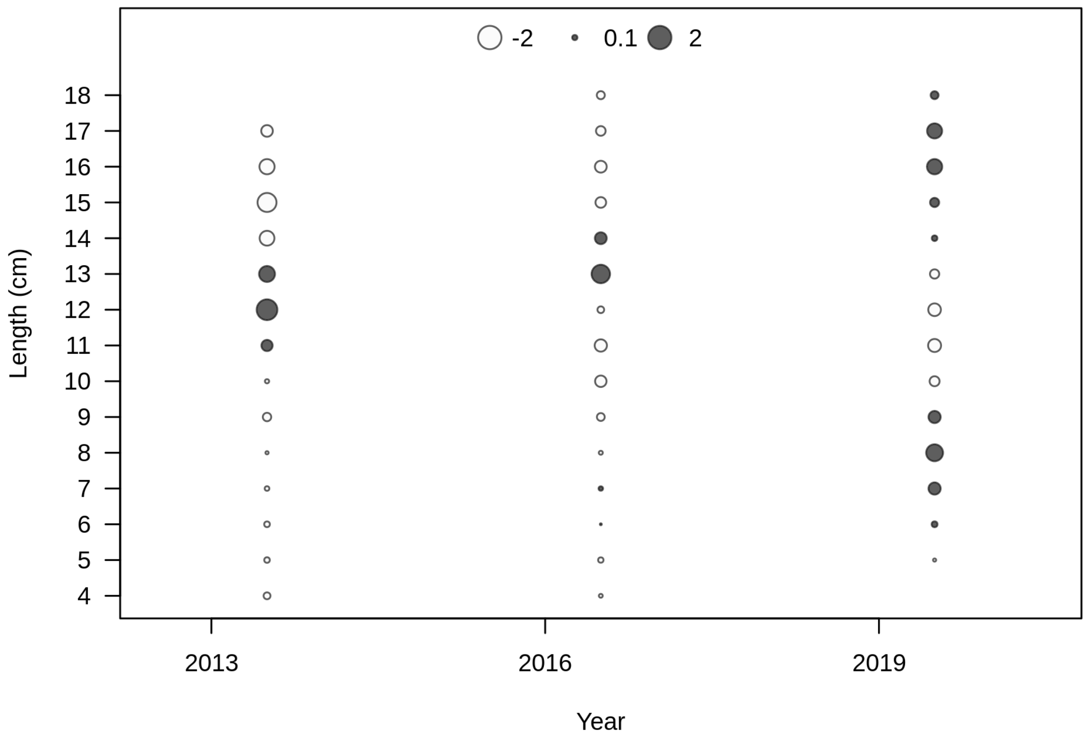



Figure 98: Pearson residuals from the fit to NEFSC survey (MCDN) length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

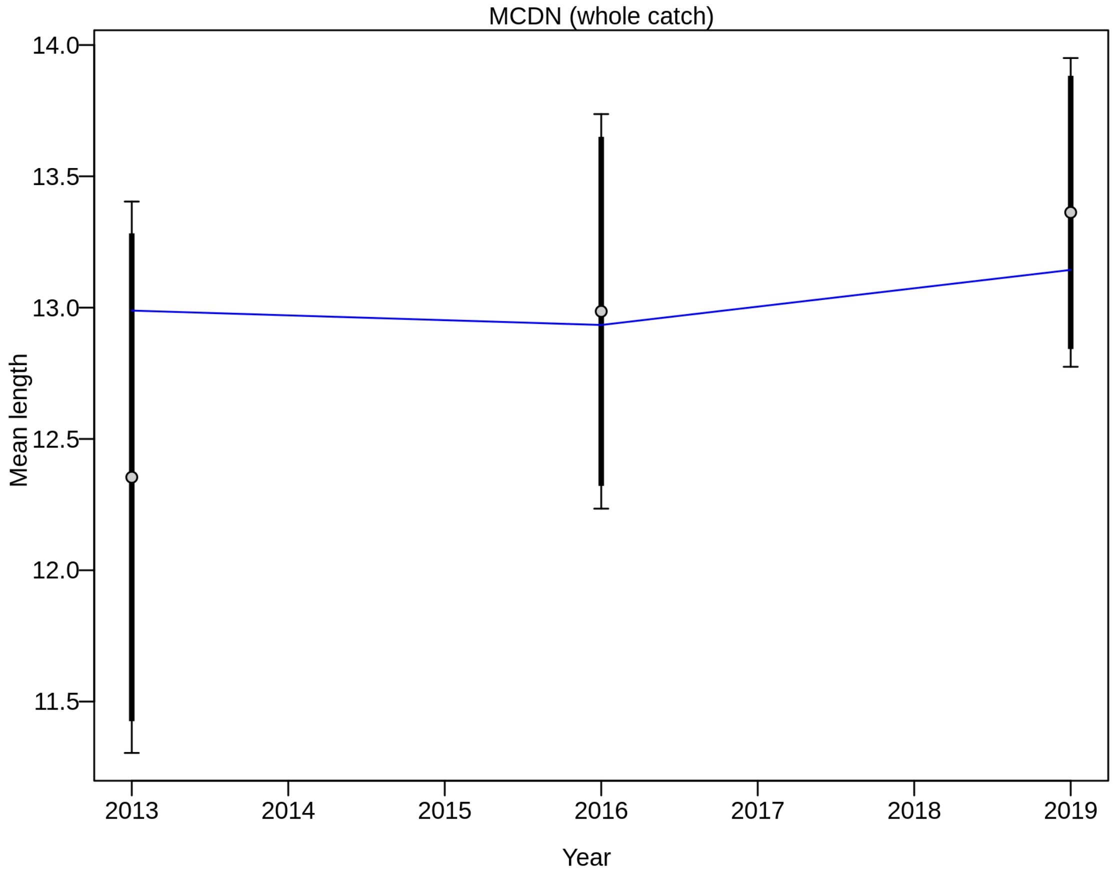



Figure 99: Observed mean length vs. the mean length predicted by the model based on fits to NEFSC survey (MCDN) length composition data used in the assessment model for Atlantic surfclam.

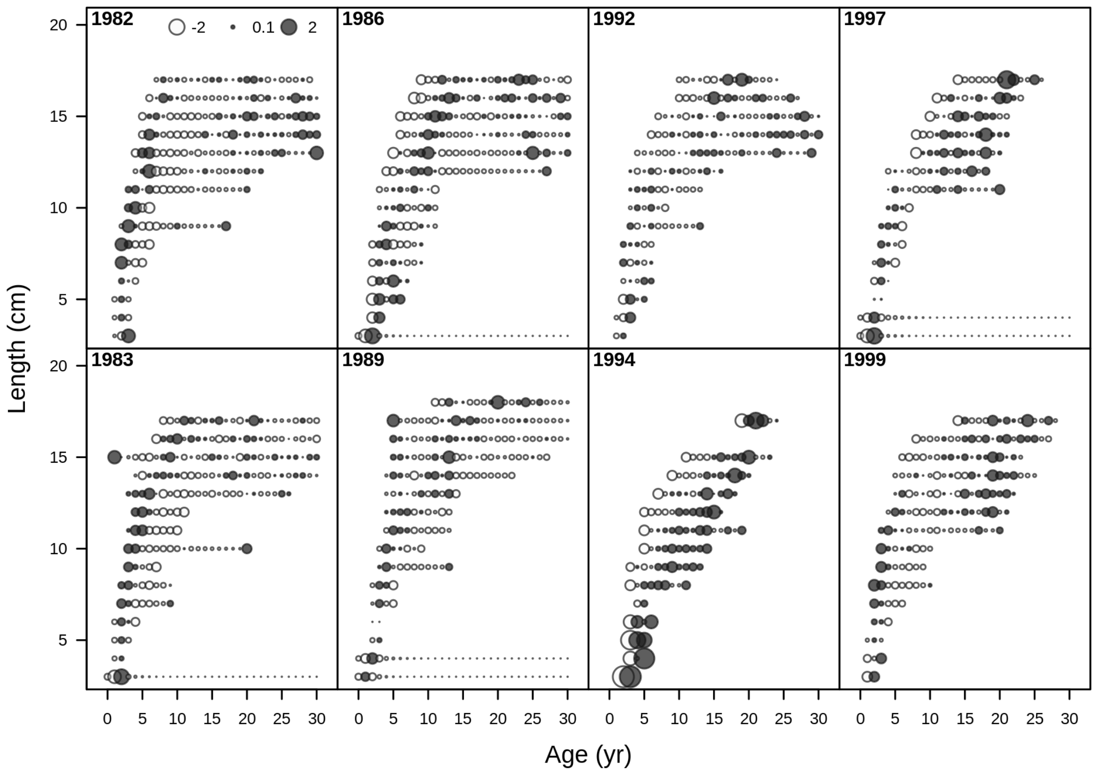



Figure 100: Pearson residuals from the fit to NEFSC survey (RDtrendS) conditional age at length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

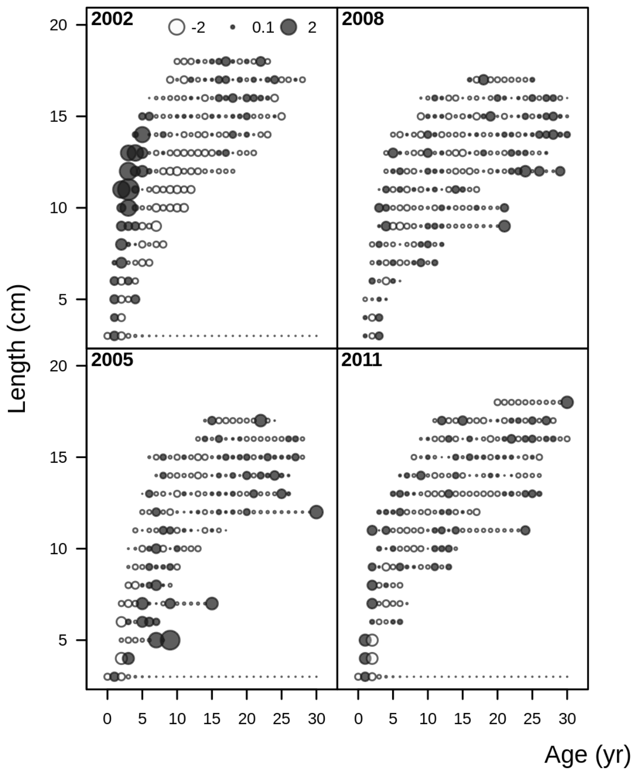



Figure 100 cont.

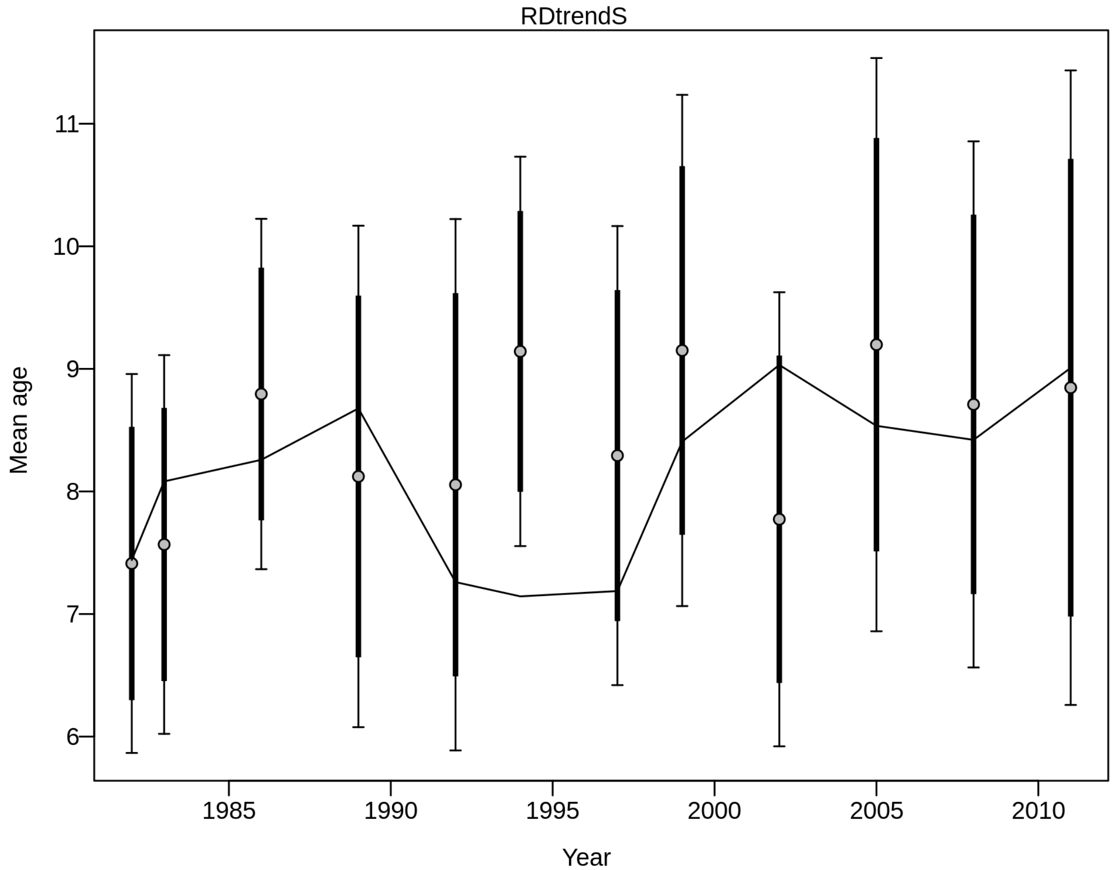



Figure 101: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RDtrendS) age at length conditional composition data used in the assessment model for Atlantic surfclam. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

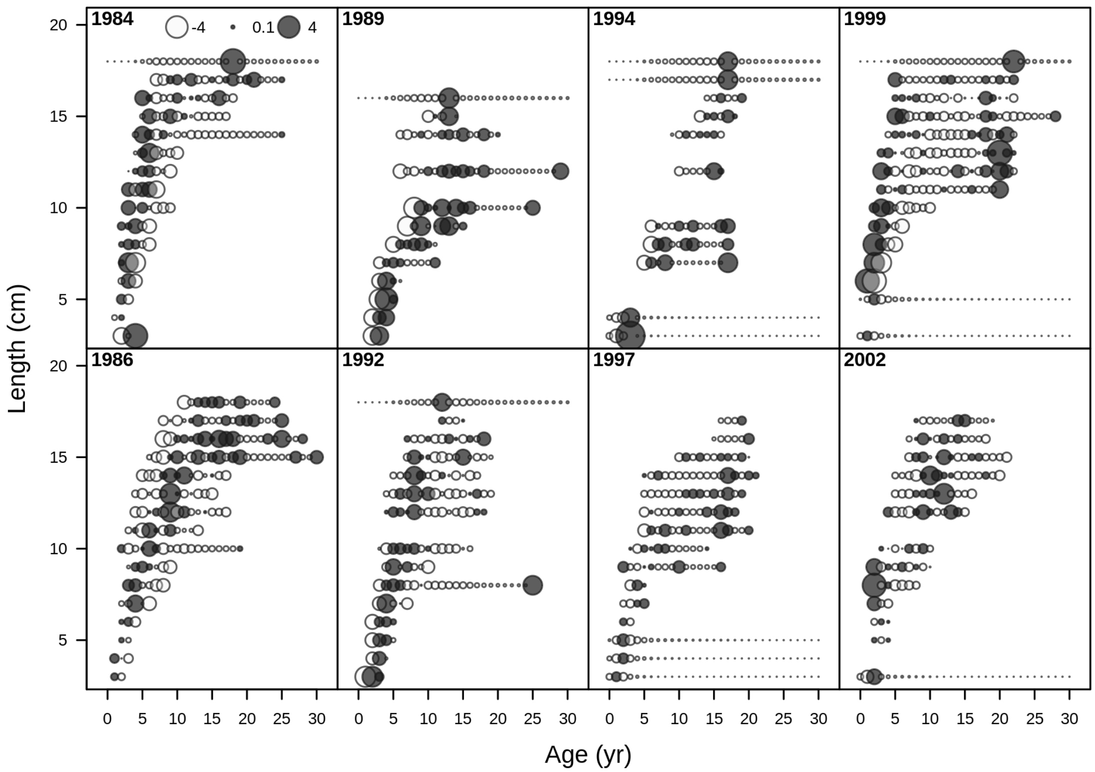



Figure 102: Pearson residuals from the fit to NEFSC survey (RDtrendN) conditional age at length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

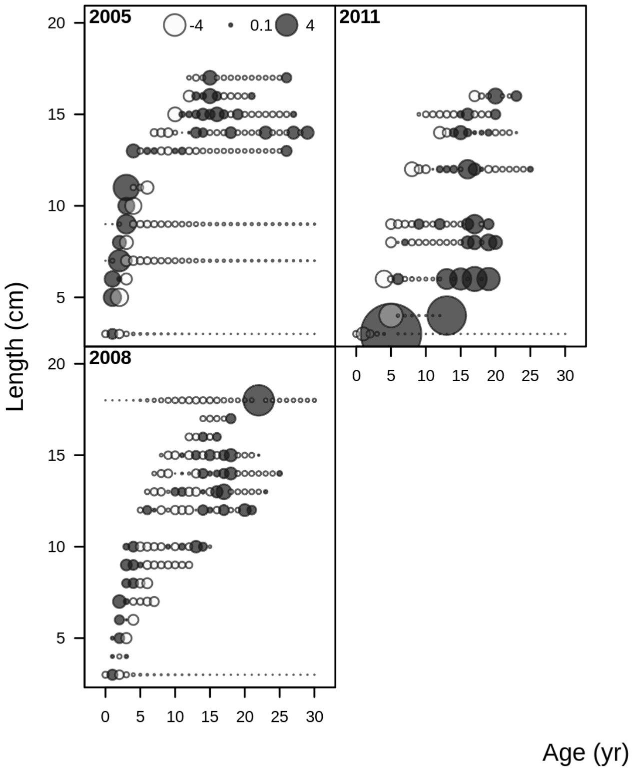



Figure 102 cont.

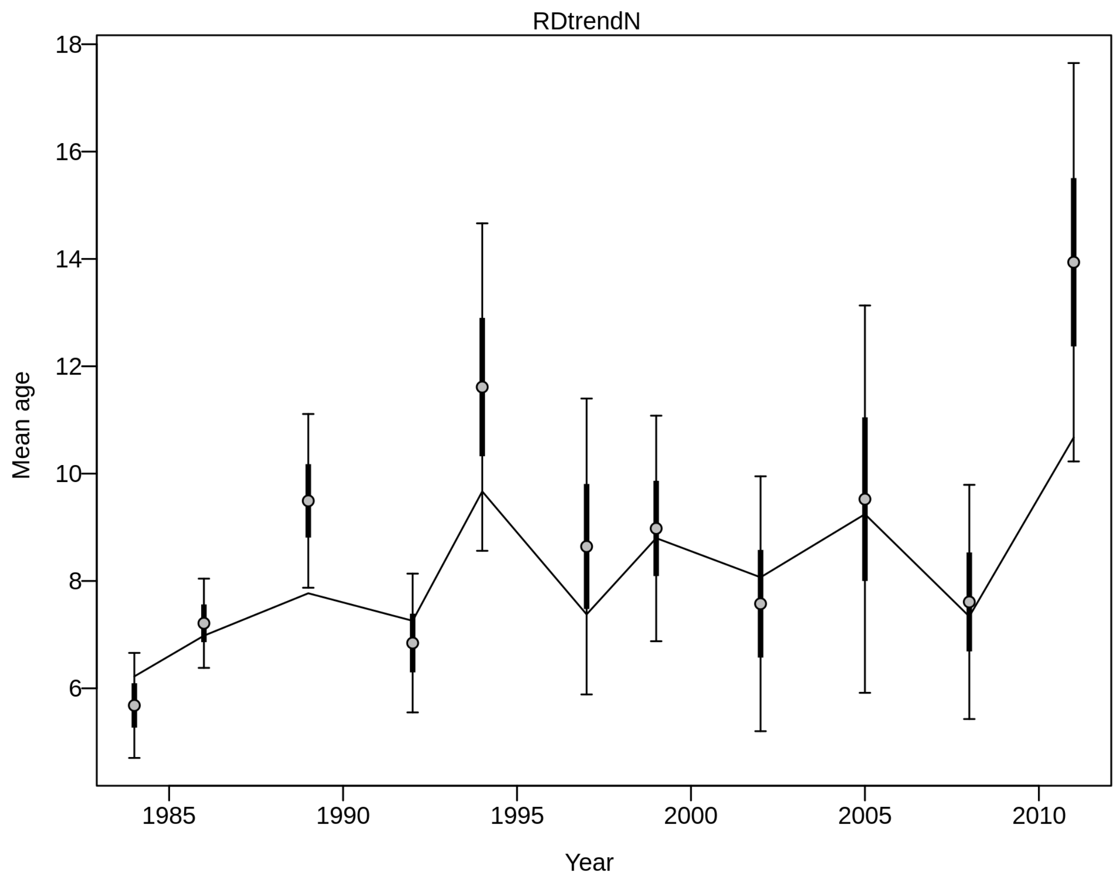



Figure 103: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (RDtrendN) age at length conditional composition data used in the assessment model for Atlantic surfclam. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

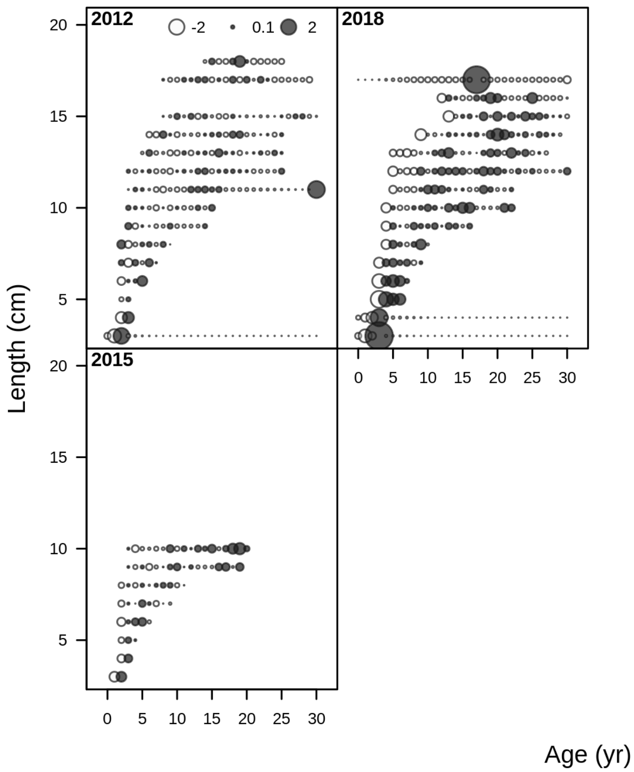



Figure 104: Pearson residuals from the fit to NEFSC survey (MCDS) conditional age at length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

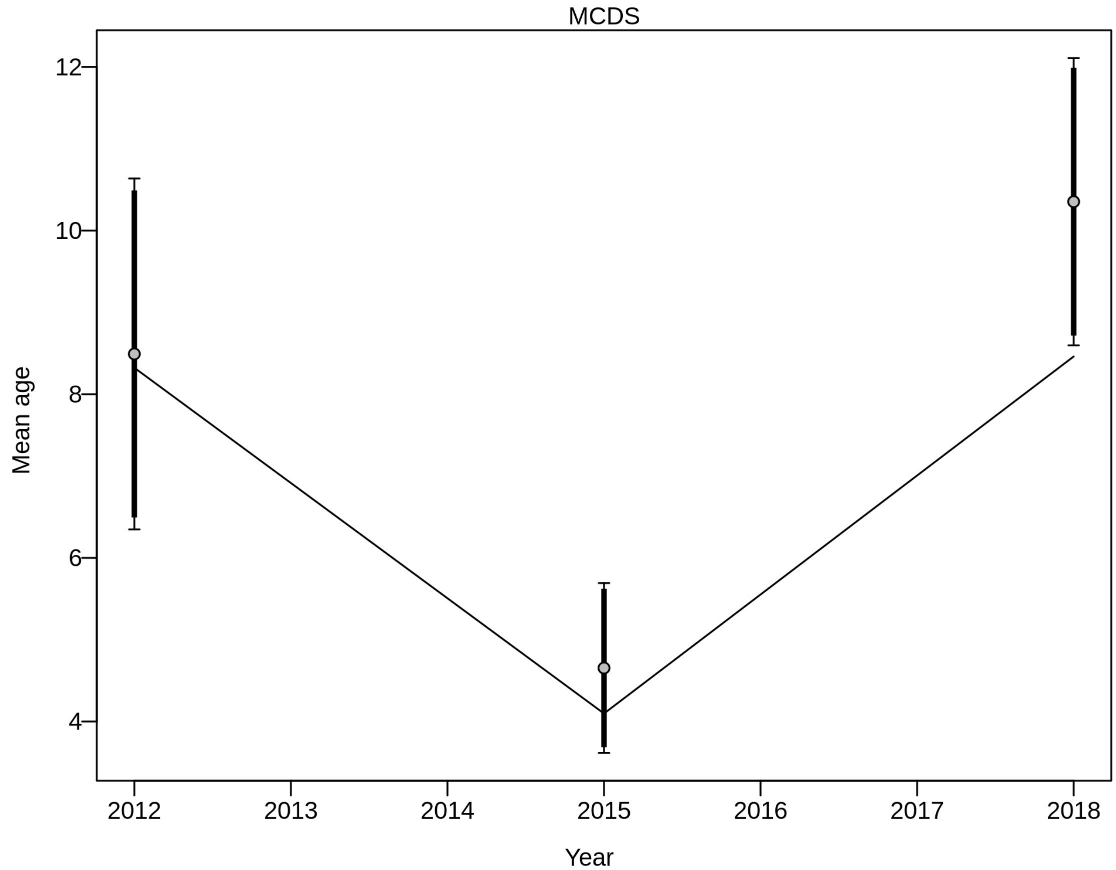



Figure 105: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (MCDS) age at length conditional composition data used in the assessment model for Atlantic surfclam. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

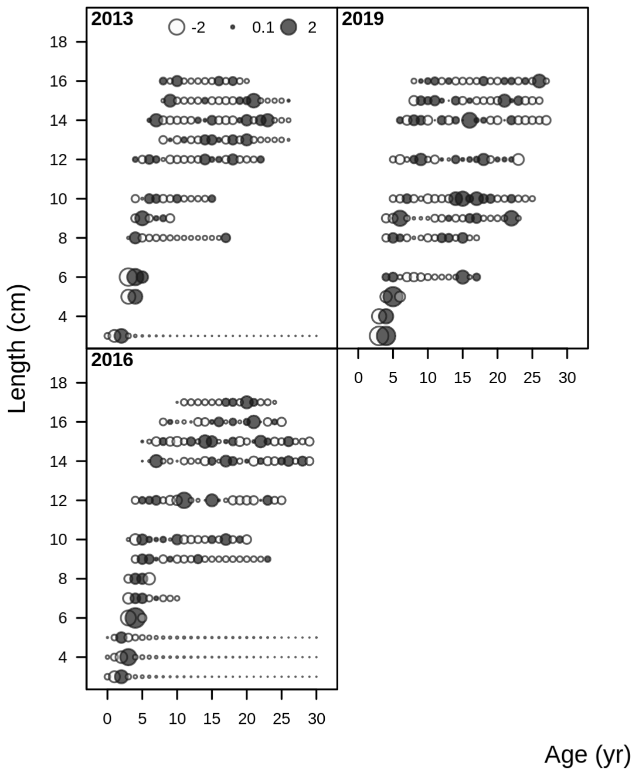



Figure 106: Pearson residuals from the fit to NEFSC survey (MCDN) conditional age at length composition data used in the assessment model for Atlantic surfclam. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

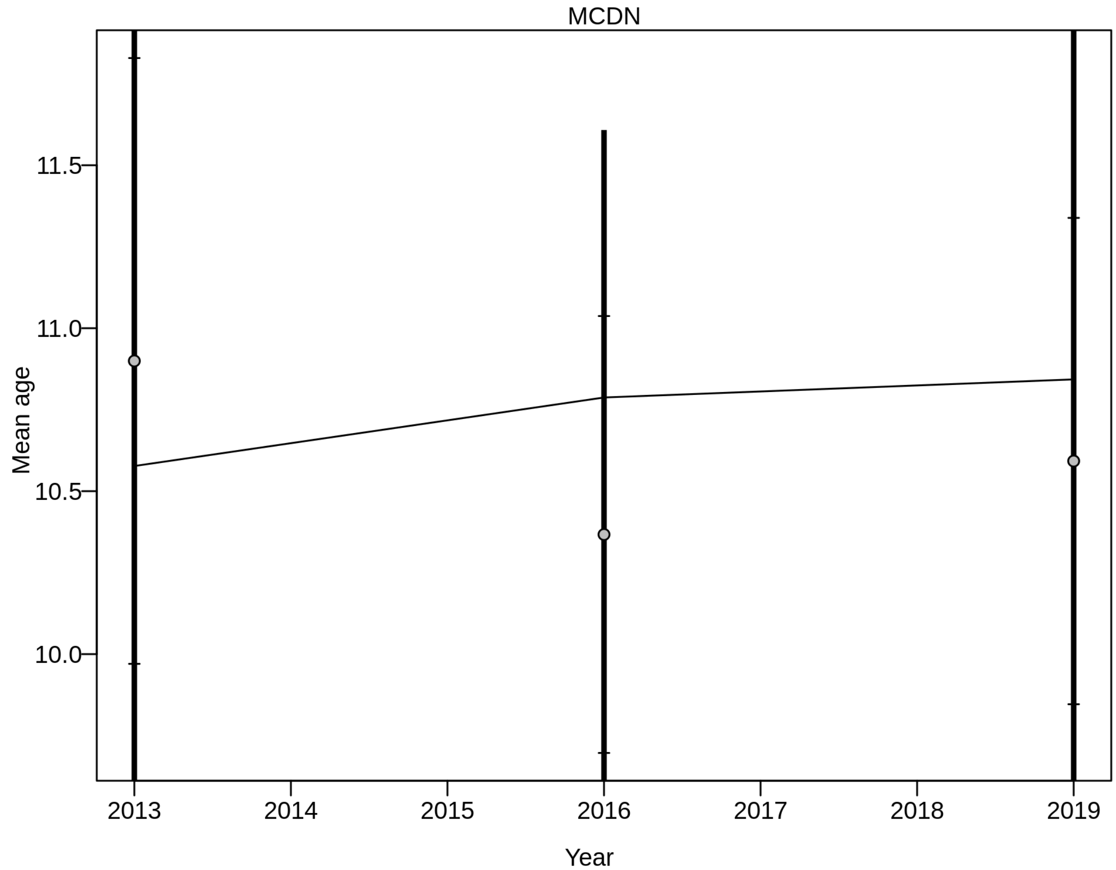



Figure 107: Observed mean age vs. the mean age predicted by the model based on fits to NEFSC survey (MCDN) age at length conditional composition data used in the assessment model for Atlantic surfclam. The thicker vertical lines show the standard deviation of the observed data and the thinner lines show the standard deviation after accounting for the data weighting adjustments used in the model.

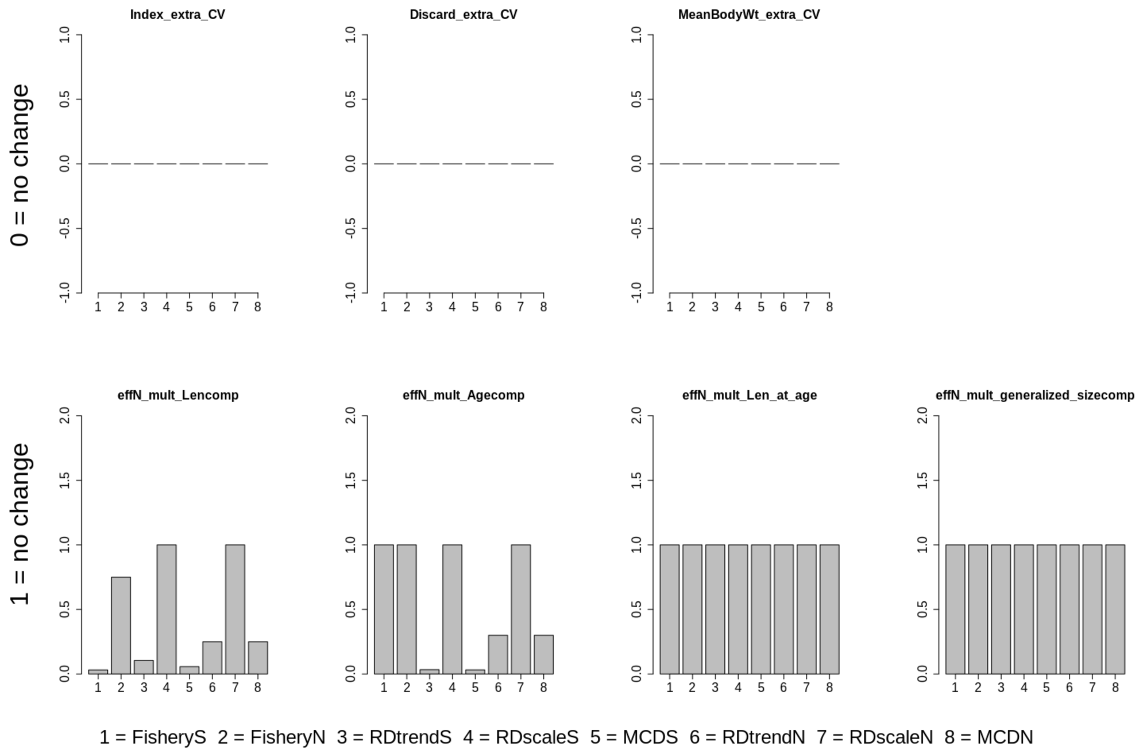



Figure 108: Adjustments made to variance components of model parameters used in the assessment model for Atlantic surfclam. The bar plots reflect data weighting decisions. In the top row deviations from 0 are the amount added to the standard deviation around input parameters. In the bottom row, the value shown in the bar plot is multiplied by the input effective sample size associated with each composition component. Thus, for example a value of less than 1 represents a reduction in the relative weight of a component.

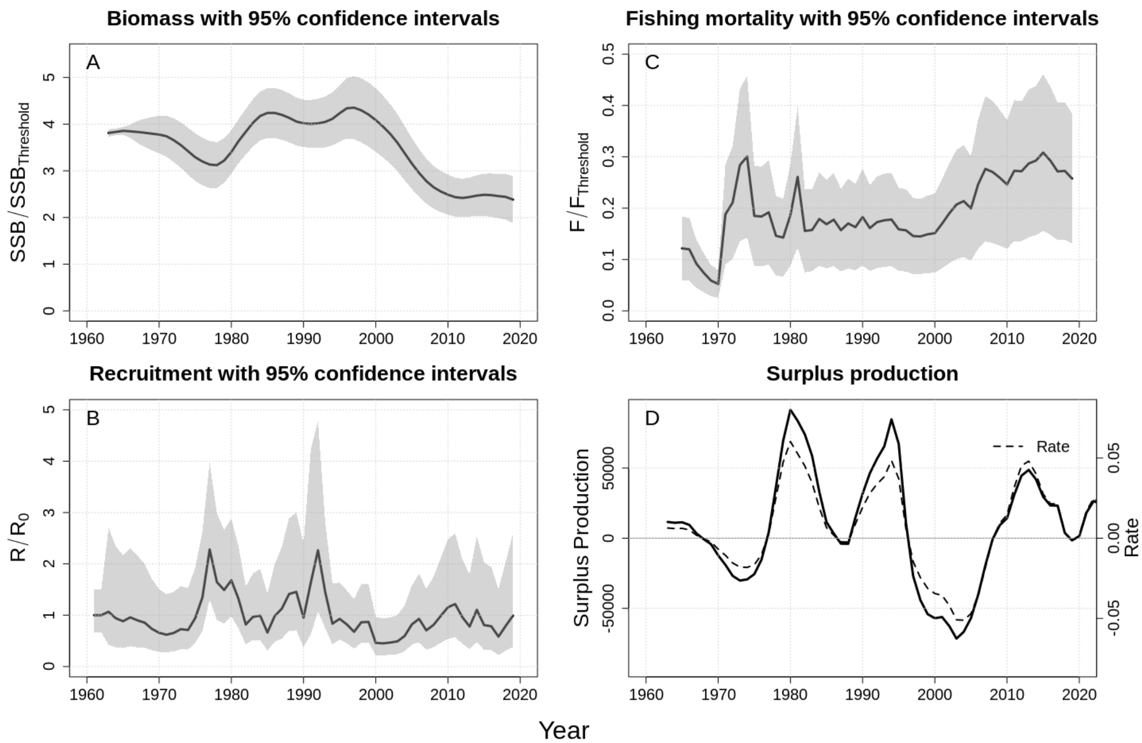



Figure 109: Estimated SSB and approximate 95% asymmetric confidence interval (A), estimated recruitment and approximate 95% asymmetric confidence interval (B), estimated fully selected fishing mortality and approximate 95% asymmetric confidence interval (C), and surplus production with surplus production rate (D), for the southern area.

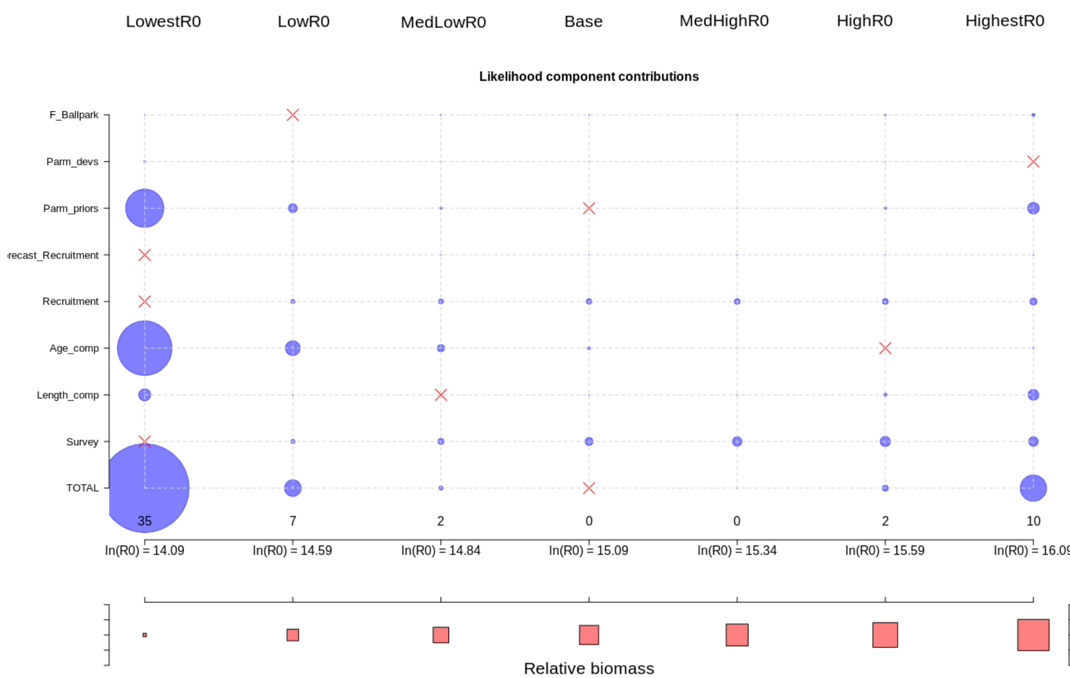



Figure 110: Likelihood profile over the virgin recruitment parameter (R0). A total of 7 model runs are depicted here. In each case, the R0 parameter was fixed at a different value. The columns of the large plot show how the component and total likelihoods change as the R0 parameter is varied. Only converged model runs are shown (attempts fit models with R0 between 14.0933 and 16.0933 were made). Each column of the large bubble plot represents one model run and the non-zero likelihood components in each run are shown in rows. For each row, the minimum likelihood component value was subtracted from each individual value, such that the minimum value in each row is represented by a red x. Bubbles are proportional to the values of each likelihood component in each run. The base value for R0 is the value at the model solution (middle column). The difference (in likelihood units) between each column and the minimum total likelihood is shown just above the x axis. Conflicts within the data are apparent when the minimum likelihood values (red x's) occur in different columns for each row. The red boxes show the relative difference in estimated terminal year biomass between runs.

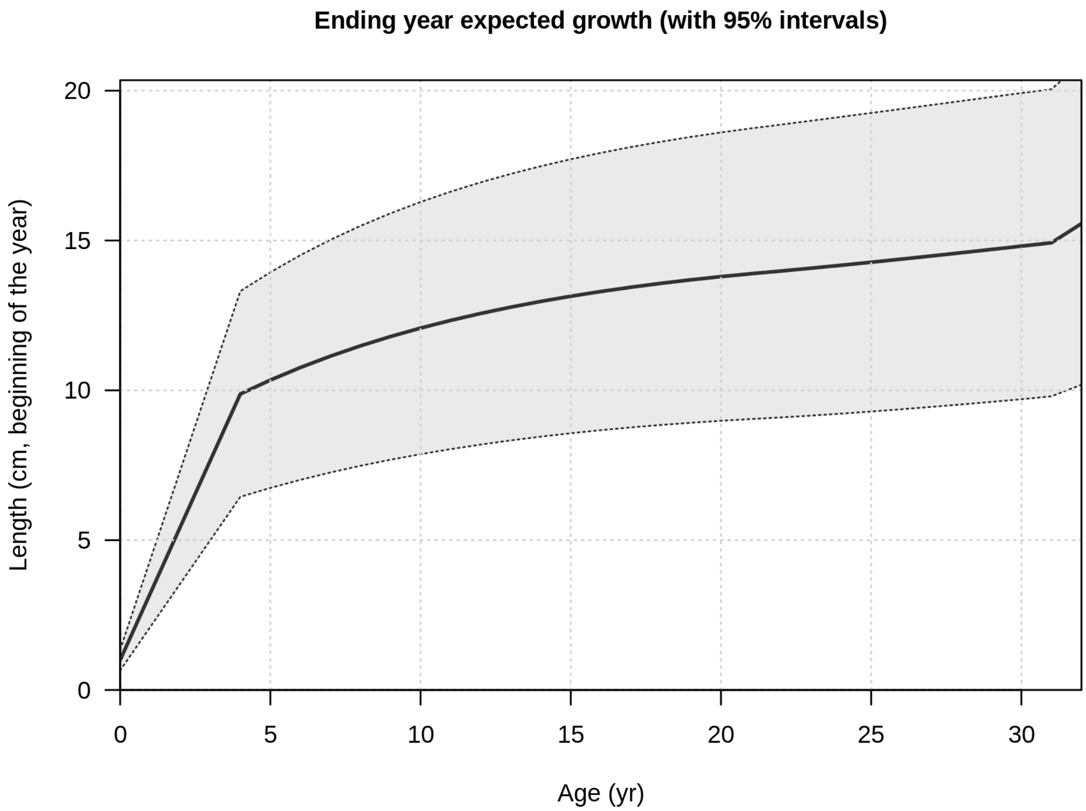



Figure 111: The growth curve resulting from forcing an increased the cv on $L_\infty$.

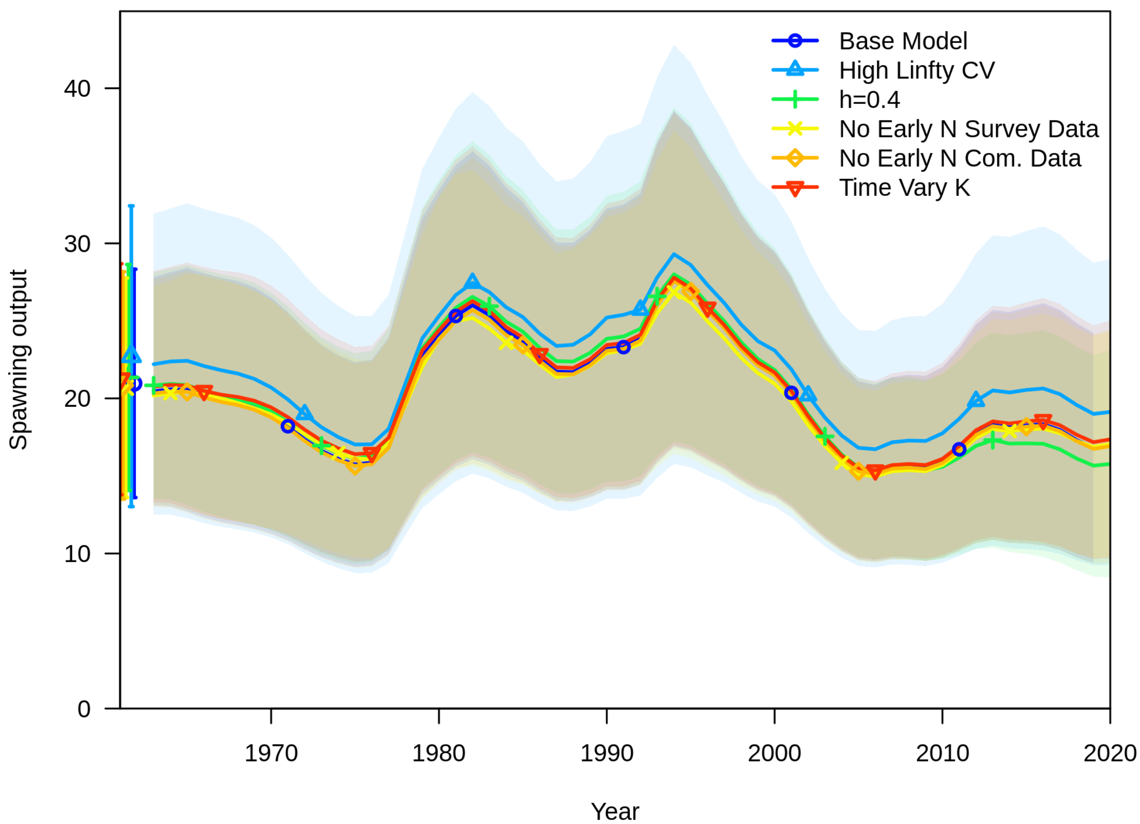



Figure 112: A comparison of the spawning output trajectories from various sensitivity runs, including: the base model (Base Model), increasing the cv on $L_\infty$ (High Linfty CV), a low, fixed steepness value (h=.4), removing early survey data from the northern area (No Early N Survey Data), removing early commercial data from the northern area (No Early N. Com. Data), and allowing the growth parameter $K$ to vary through time (Time Vary K).

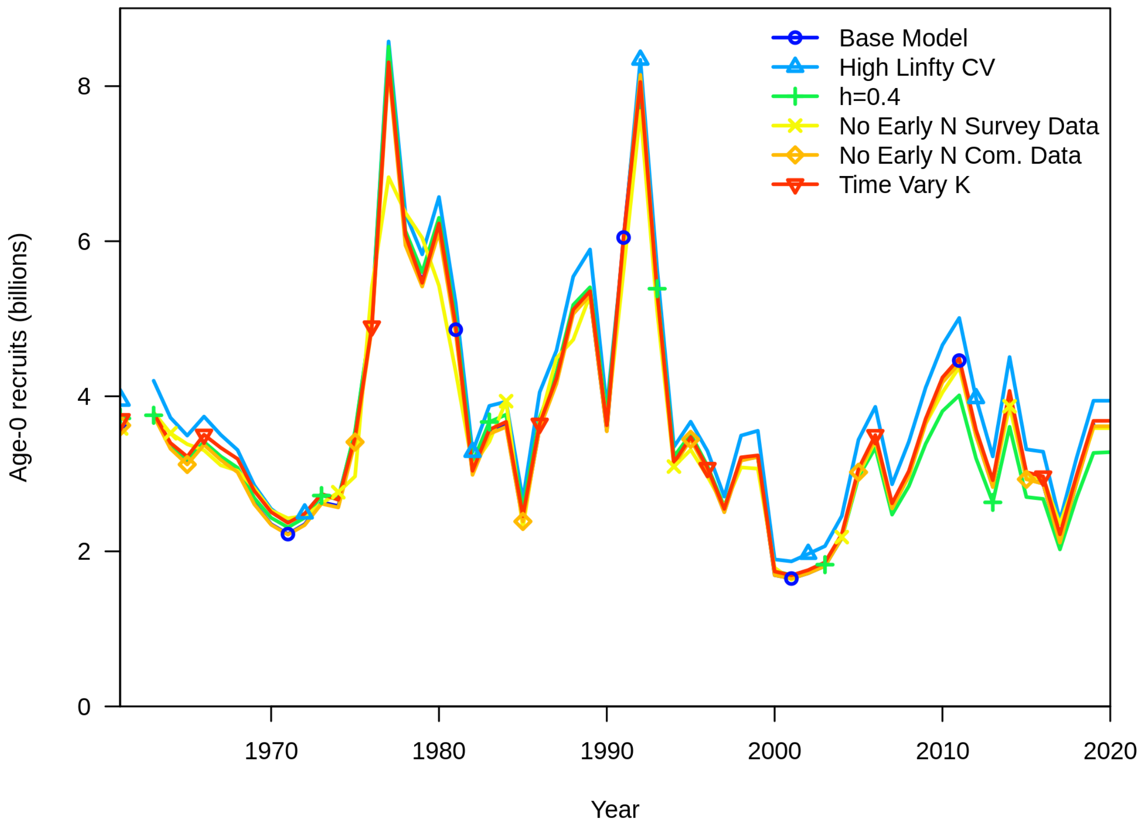



Figure 113: A comparison of the recruitment trajectories from various sensitivity runs, including: the base model (Base Model), increasing the cv on $L_\infty$ (High Linfty CV), a low, fixed steepness value (h=.4), removing early survey data from the northern area (No Early N Survey Data), removing early commercial data from the northern area (No Early N. Com. Data), and allowing the growth parameter $K$ to vary through time (Time Vary K).

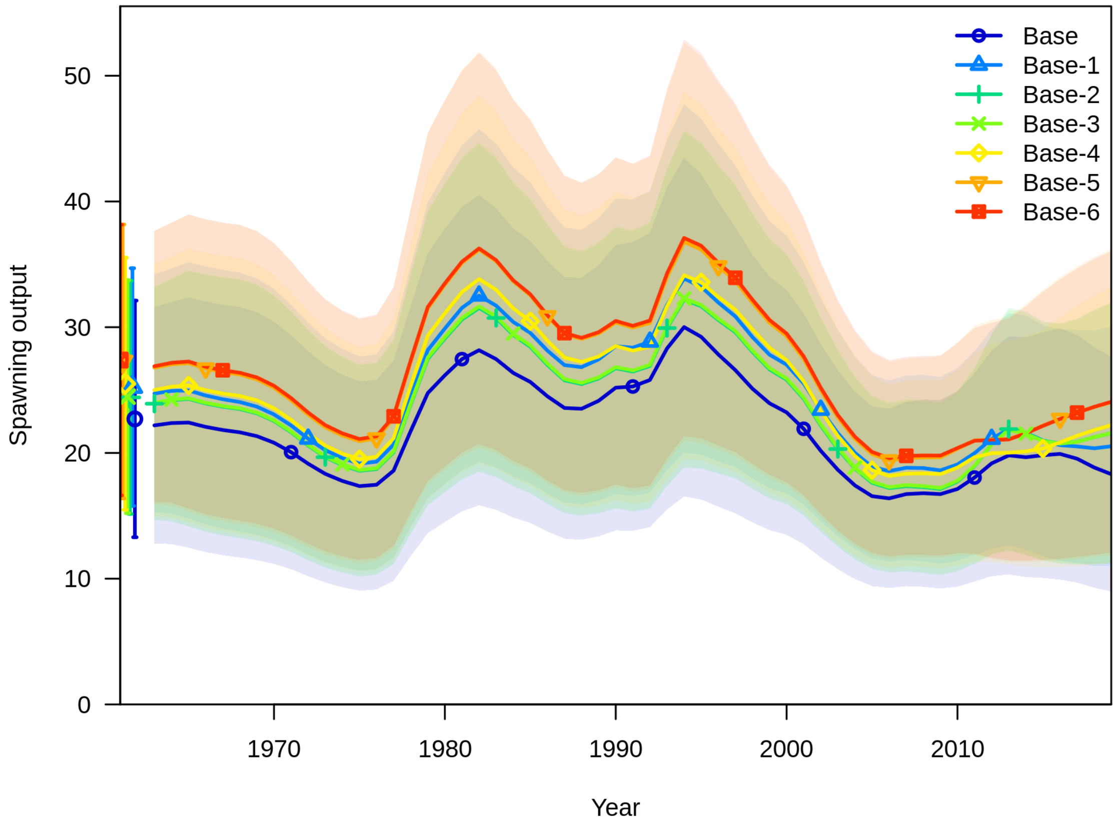



Figure 114: Biomass scale and uncertainty from 6 retrospective runs of the model for Atlantic surfclam. The dashed line represents a theoretical threshold value where the biomass is equal to $25\%$ of the virgin biomass estimated in each retrospective run.

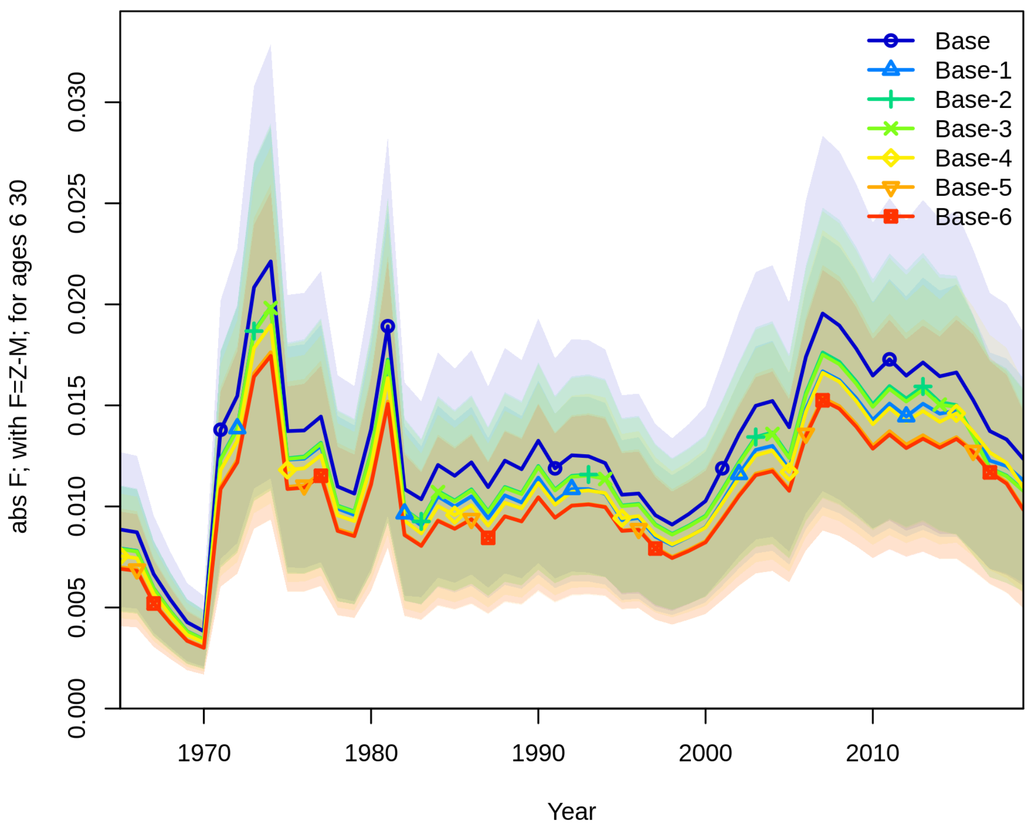



Figure 115: Fishing mortality and uncertainty from 6 retrospective runs of the model for Atlantic surfclam.

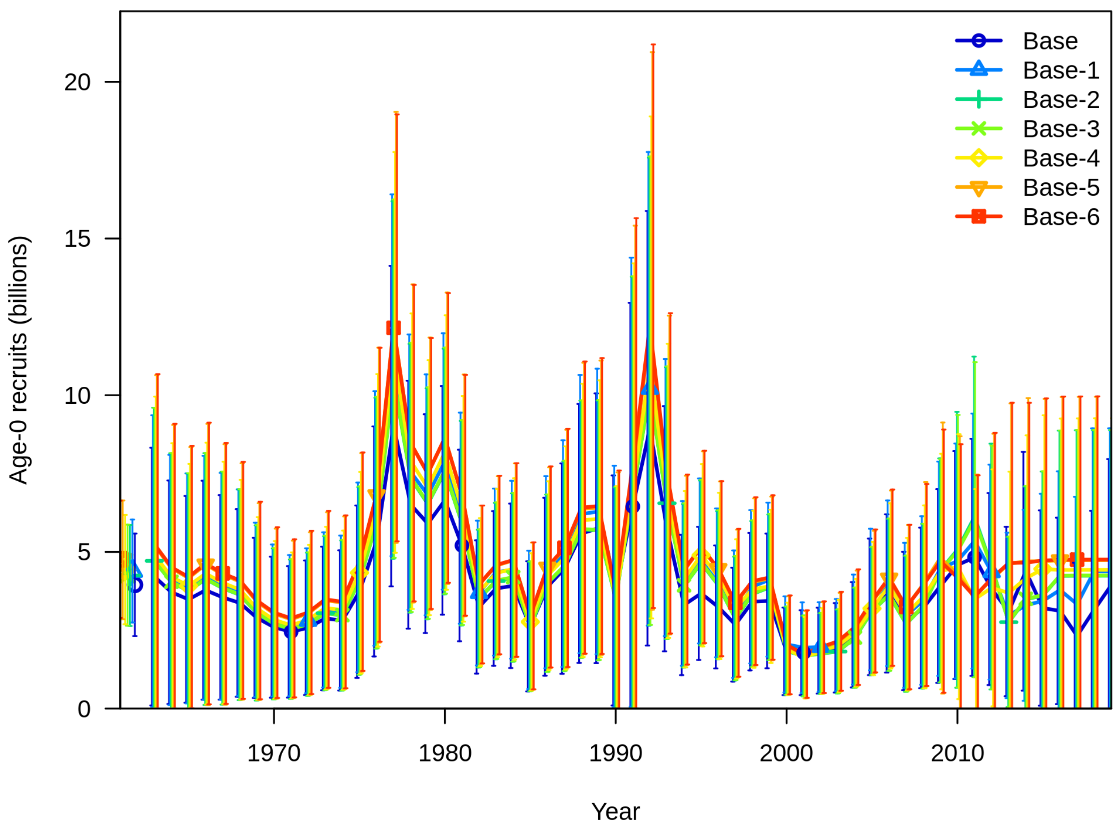



Figure 116: Recruitment and uncertainty from 6 retrospective runs of the model for Atlantic surfclam.

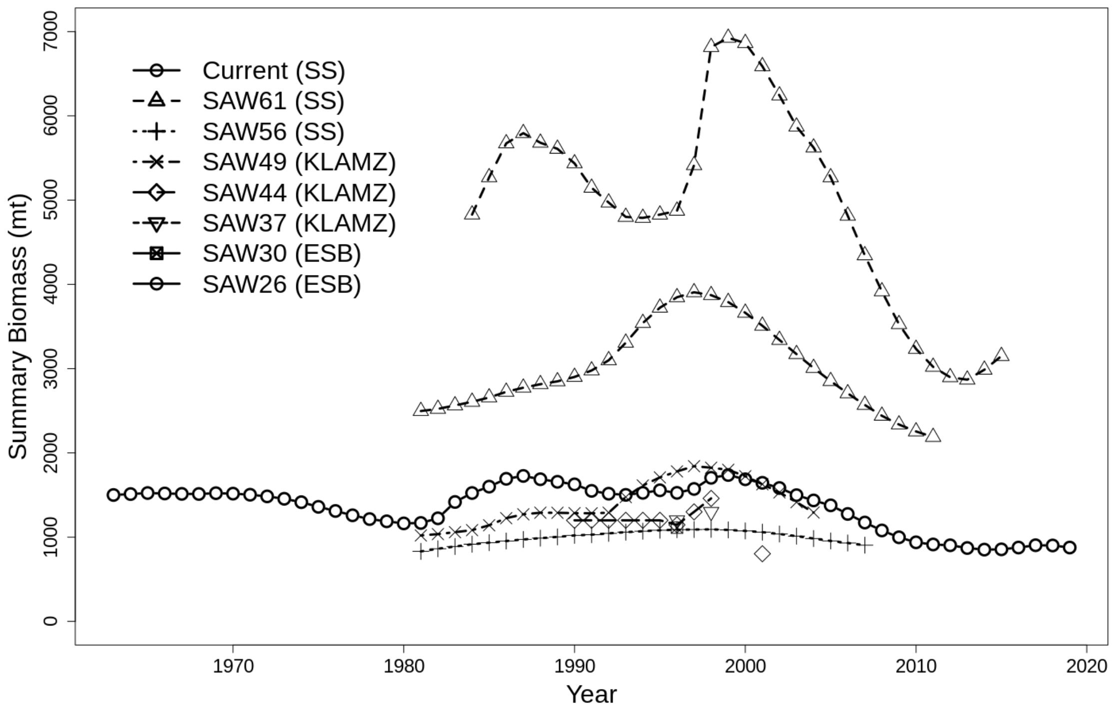



Figure 117: Historical retrospective plot showing the biomass trajectory from each of the previous Atlantic surfclam assessments.

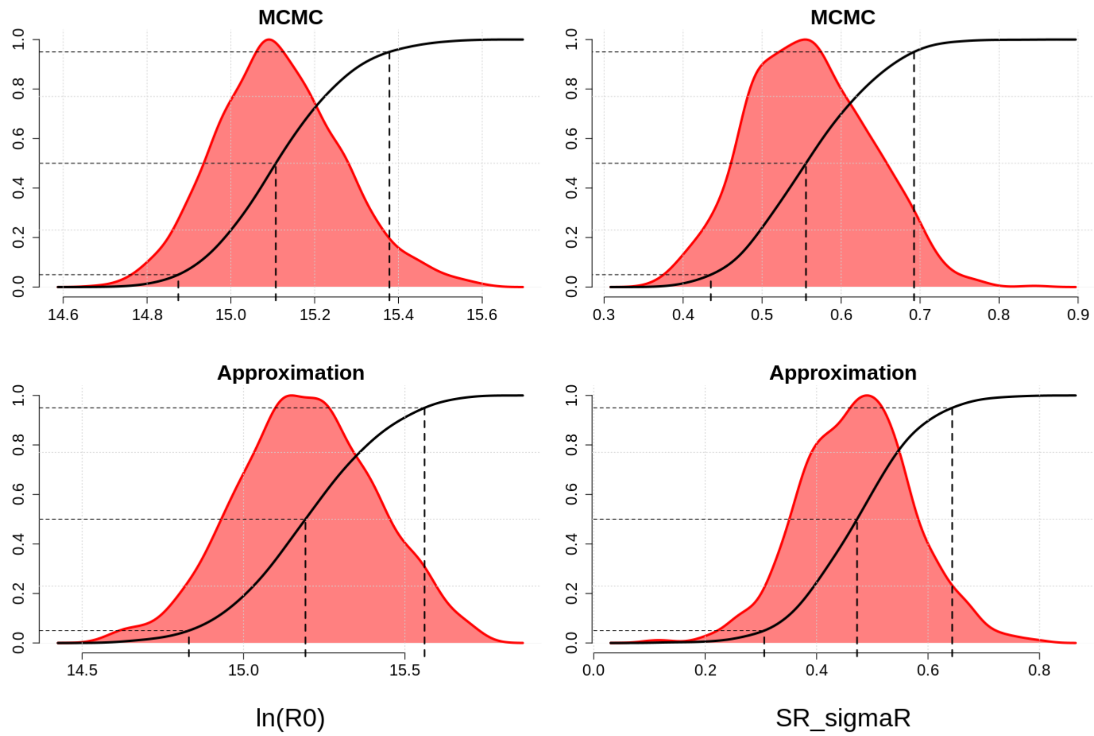



Figure 118: A comparison of the uncertainty in important stock recruitment parameters based on MCMC and delta method approximation.

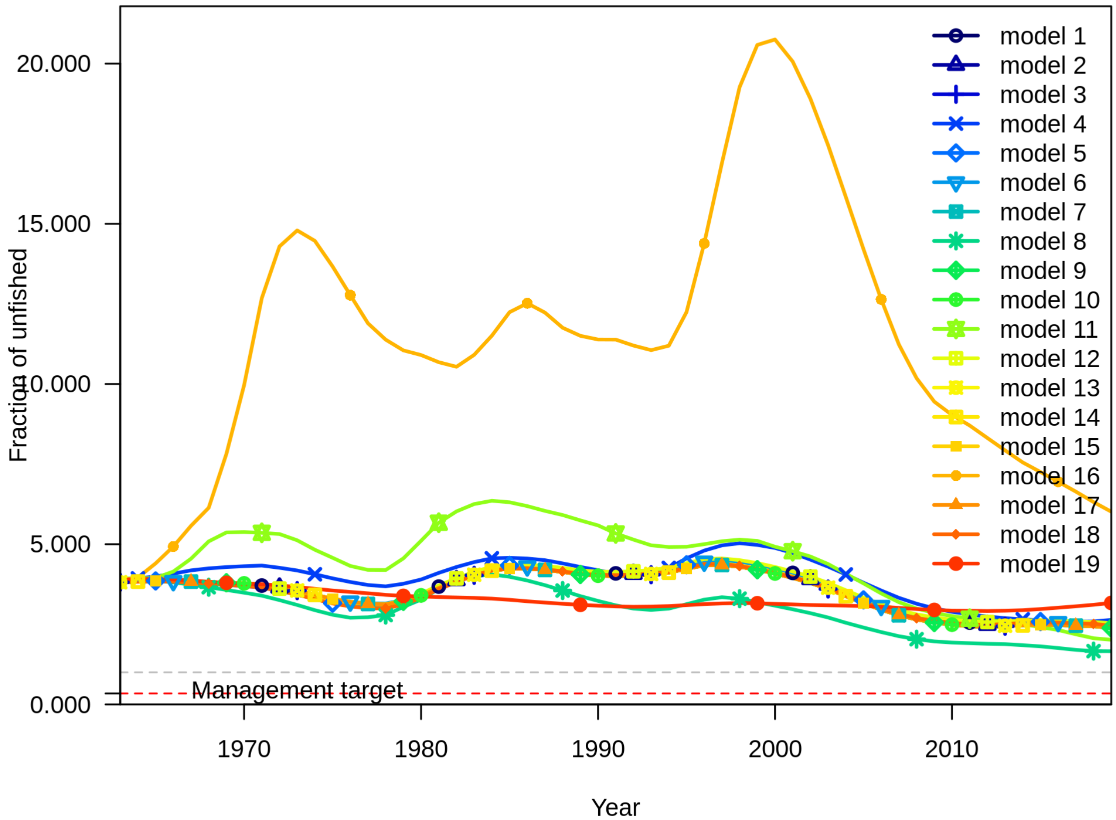



Figure 119: A comparison of the spawning output trajectories from various jitter runs in which the starting conditions for all model parameters were shifted.

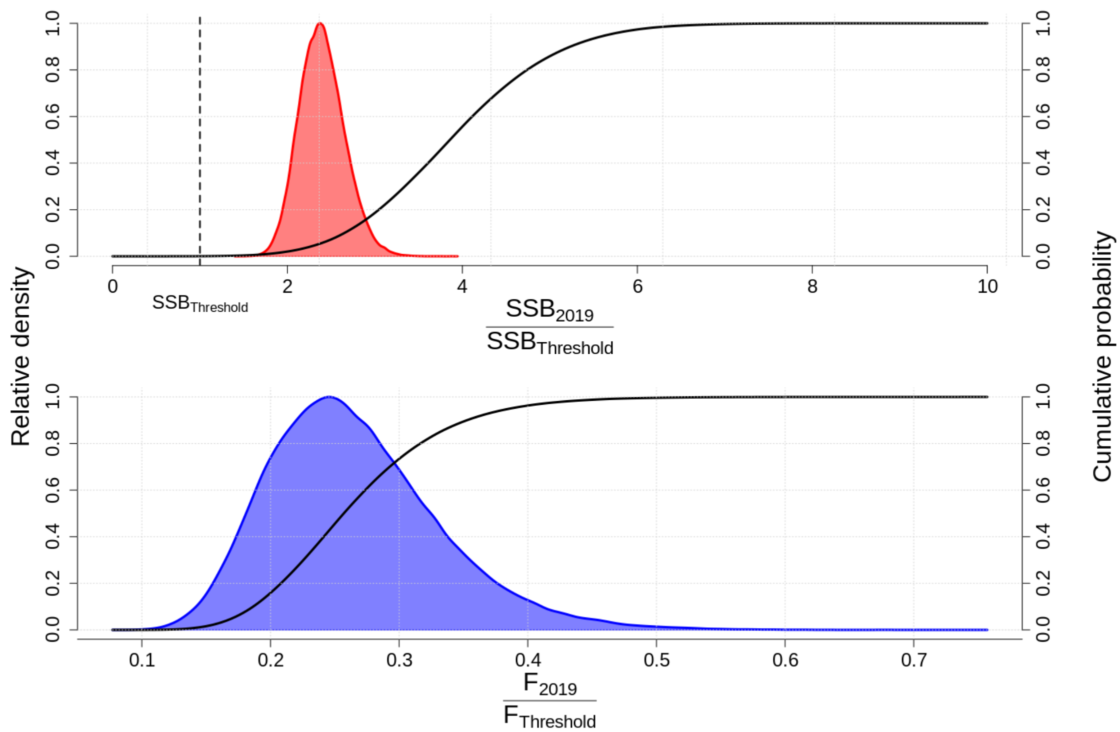



Figure 120: Probability distributions of $\frac{B_{2019}}{B_{Threshold}}$ and $\frac{F_{2019}}{F_{Threshold}}$, using the recommended reference points. The probability of overfished status during 2019 is equal to the area of the red, upper curve that is less than $B_{Threshold}$. The probability of overfishing status during 2019 is equal to the area of the blue, lower curve that is greater than $F_{Threshold}$. The probability of overfished and overfishing status can be approximated by the elevation (y axis scale) at which the solid line representing the cumulative probability distribution crosses the dashed vertical line representing the reference point in each plot. The probability distributions presented in this figure account for the positive correlation between the reference points ($B_{Threshold} = \frac{B_0}{4}$ and $F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$) and the fishing mortality and biomass estimates in 2019, as well as the uncertainty in the estimation of both the point estimates and their respective reference points.

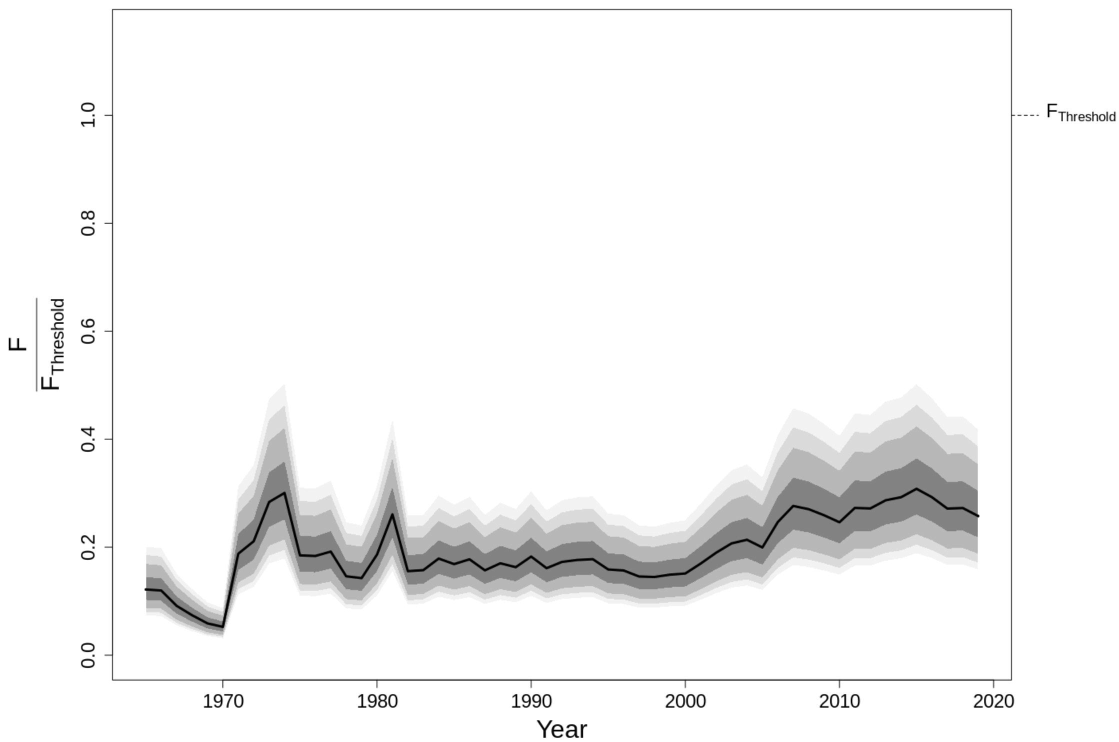



Figure 121: The time series of the ratio of fishing mortality estimates to the recommended $F$ threshold, with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between $F$ and $F_{Threshold}$. Over fishing would occur if the ratio exceed 1.0.

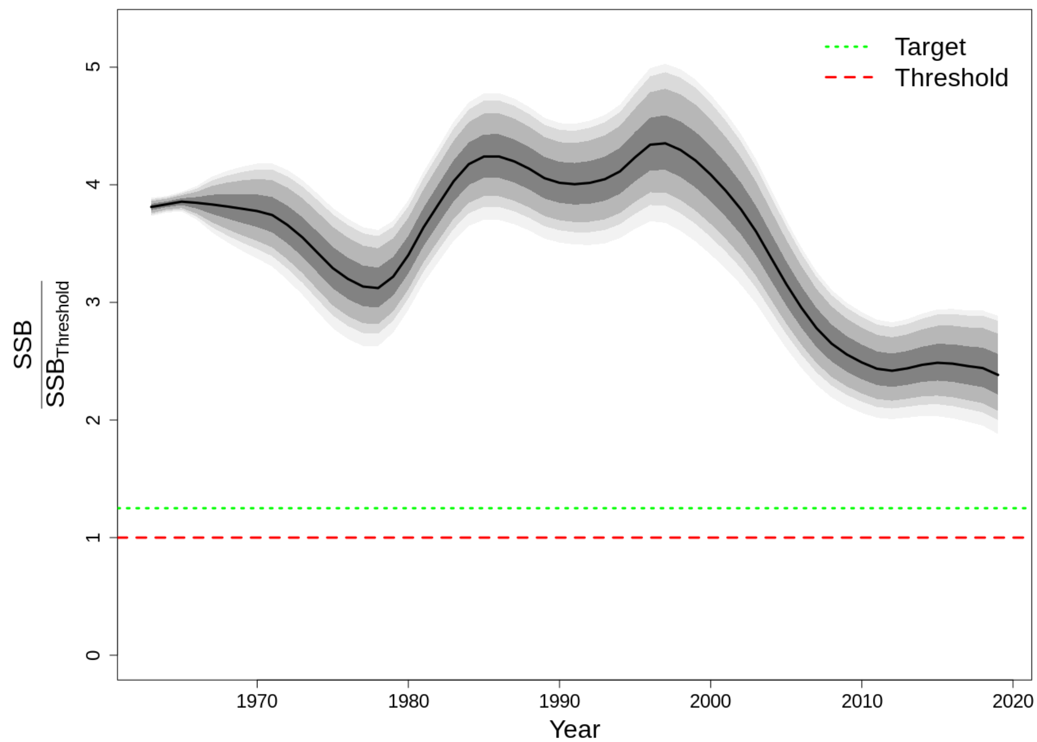



Figure 122: The time series of the ratio of biomass estimates to the unfished biomass ($B_0$), with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between $B$ and $B_0$. Overfished status would occur if the ratio went below 0.25.

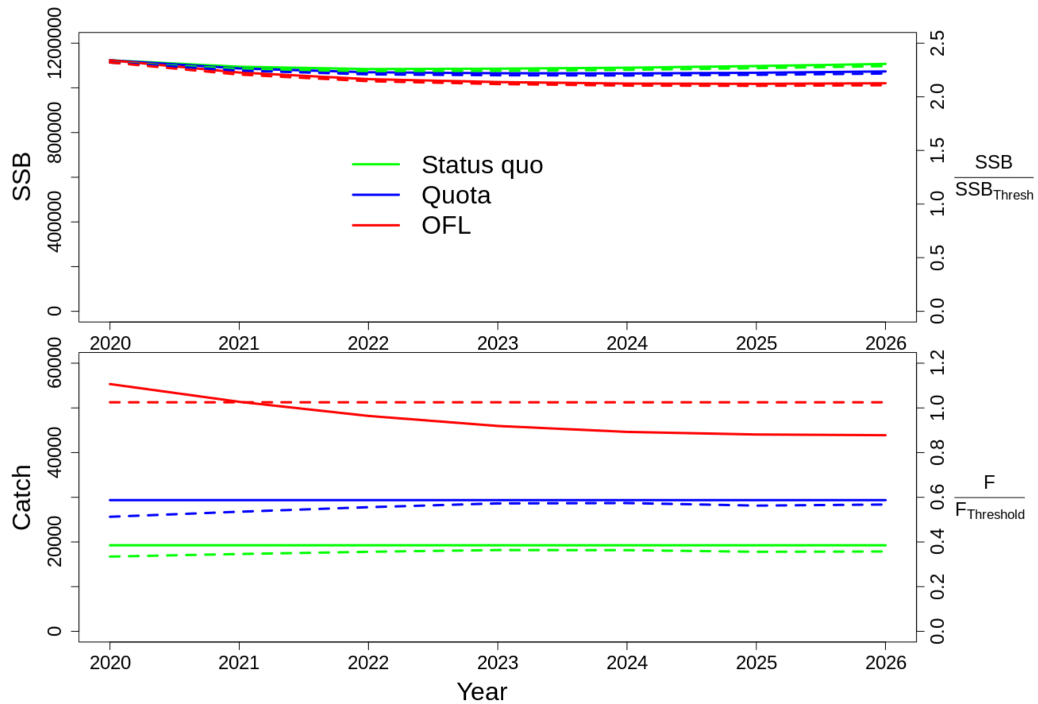



Figure 123: Projections using three different catch scenarios in the southern, northern and whole stock areas. The upper row of plots show the biomass trends over time (solid lines) and the ratio of biomass to biomass threshold (dashed lines). The lower plots show the landings (solid lines) and the ratio of $F$ to $F_{OFL}$. In all plots the status quo catch scenario is green, the quota catch scenario is blue and the $F = F_{OFL}$ scenario is red. Determination of $\frac{F}{F_{OFL}}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

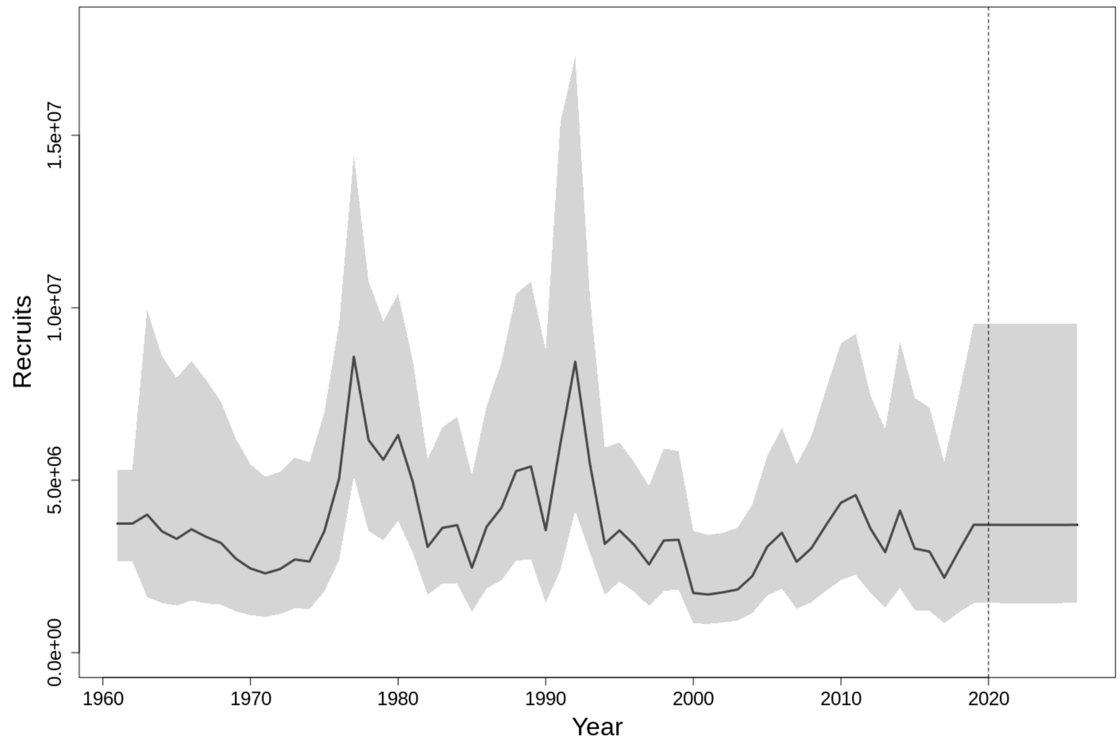



Figure 124: Forecast and time series recruitment estimates for the southern, and northern areas. Projections begin at the vertical dashed line. Note the different ranges of the vertical axes.

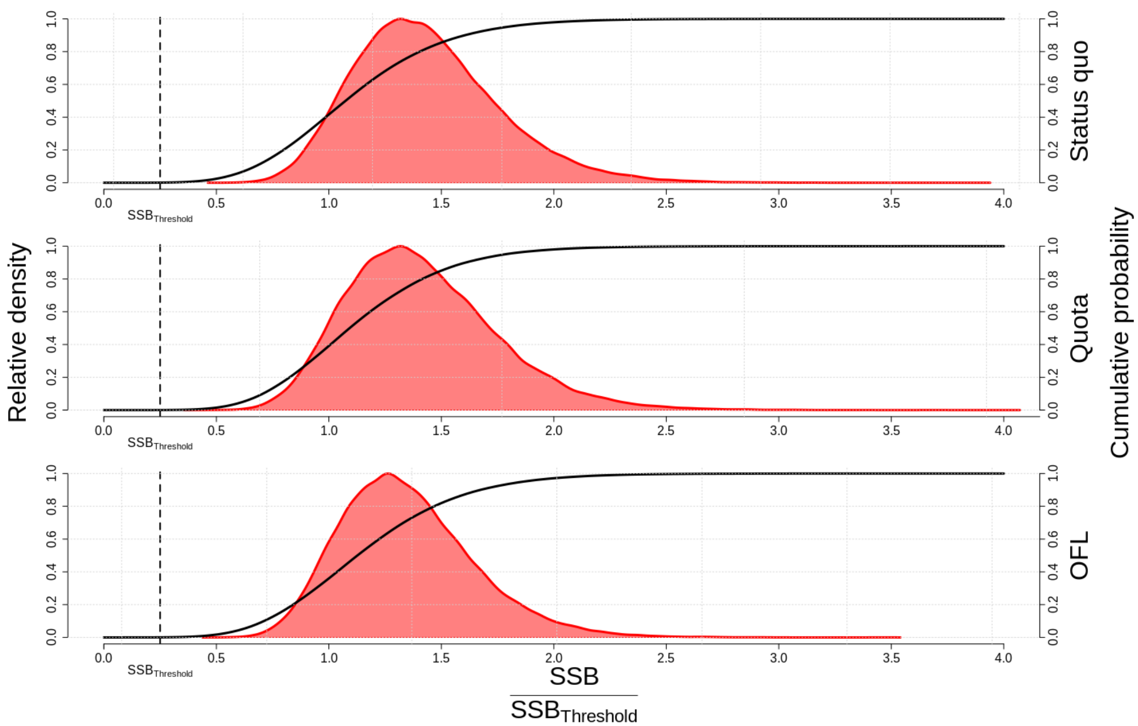



Figure 125: Probability of overfished status for Atlantic surfclam during the projection year with the lowest biomass from 2020-2026. The different catch scenarios are in rows and the different areas are in columns.

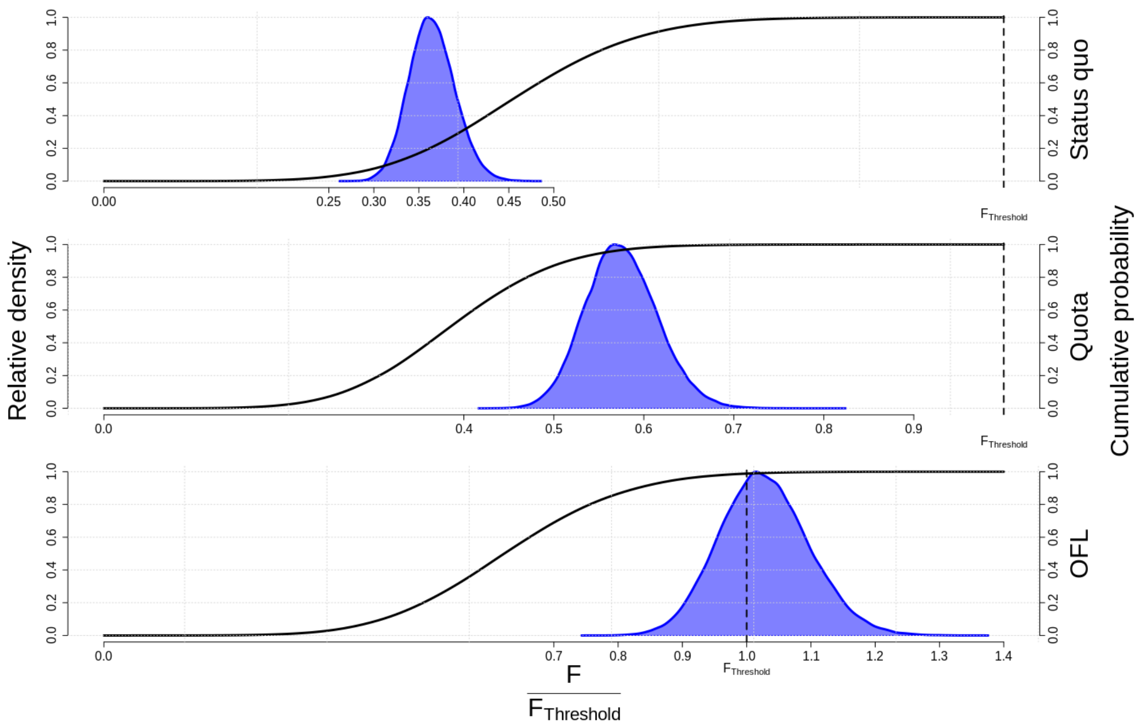



Figure 126: Probability of overfishing status for Atlantic surfclam during the projection year with the highest $F$ from 2020-2026. The different catch scenarios are in rows and the different areas are in columns. Determination of $F_{OFL}$ for the northern area was not possible due to a lack of the exploitation history required to generate an area specific fishing mortality threshold.

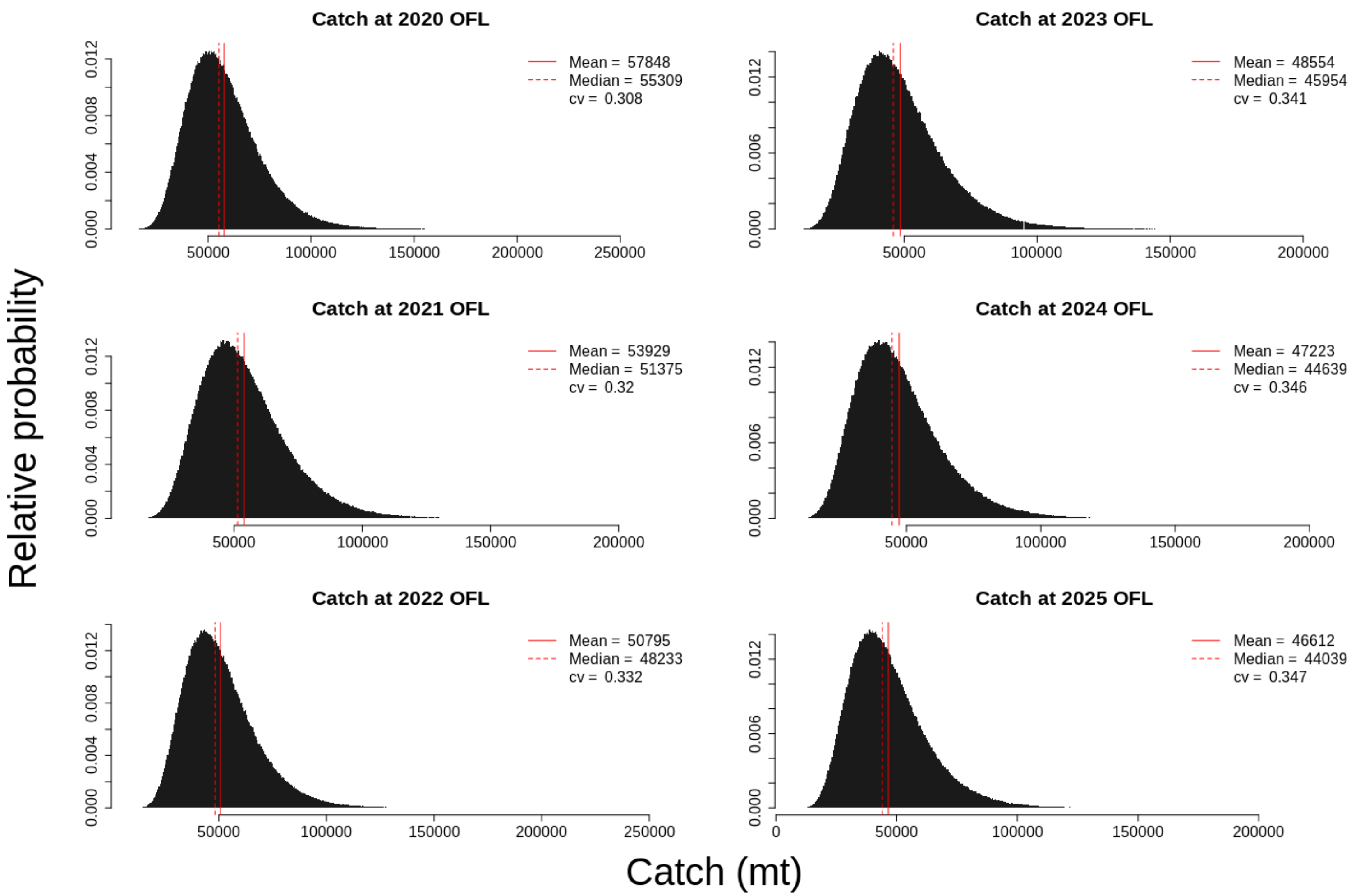



Figure 127: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2020-2026 for Atlantic surfclam in the whole stock.

## Appendix 1 VMS

A Vessel Monitoring System (VMS) is used to monitor the location and movement of commercial fishing vessels in the EEZ for certain fisheries. The system uses satellite-based communications from on-board transceiver units that report location at prescribed intervals. The VMS system reports vessel location at least once an hour in the clam fishery.

VMS data can be used to determine the approximate location of vessels during fishing operations. This is done by counting all returns (pings) from the system where the boat was moving at $<5$ knots (i.e. where the positions recorded one hour apart are less than 5 nm apart). The assumption being that any vessels moving between 0 and 5 knots are likely to be fishing rather than docked or transiting. VMS can approximate effort, and identify fishing locations, but not landings data.

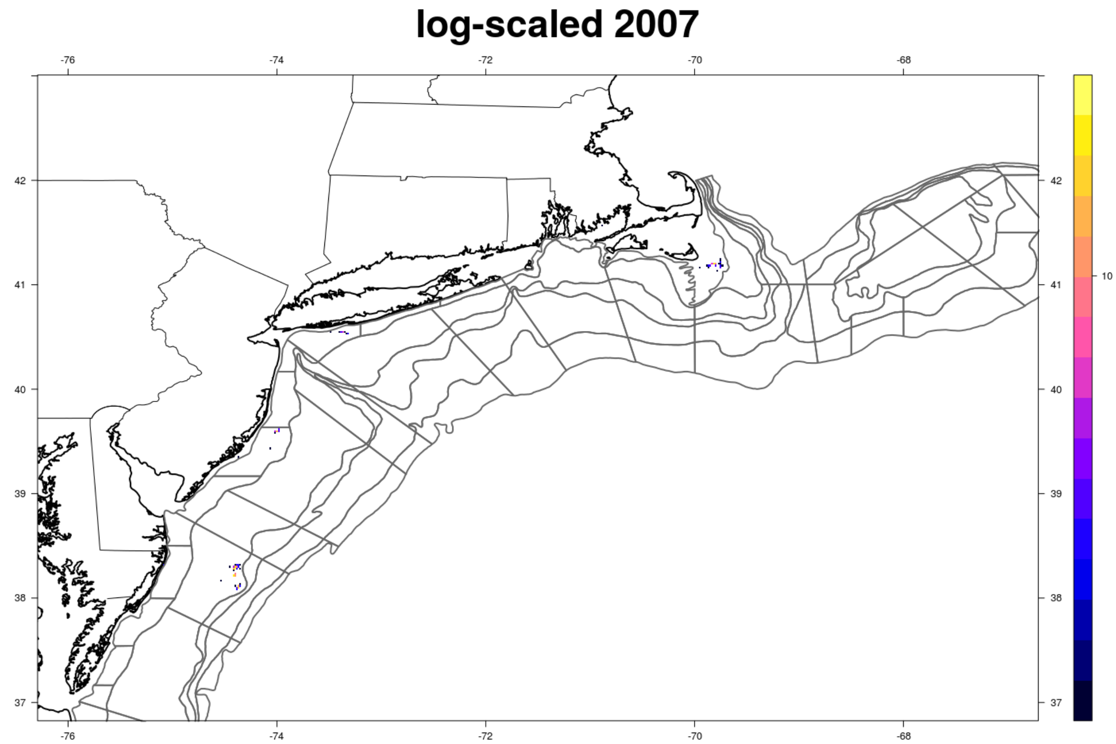



Figure 128: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2007. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2007 are not shown.

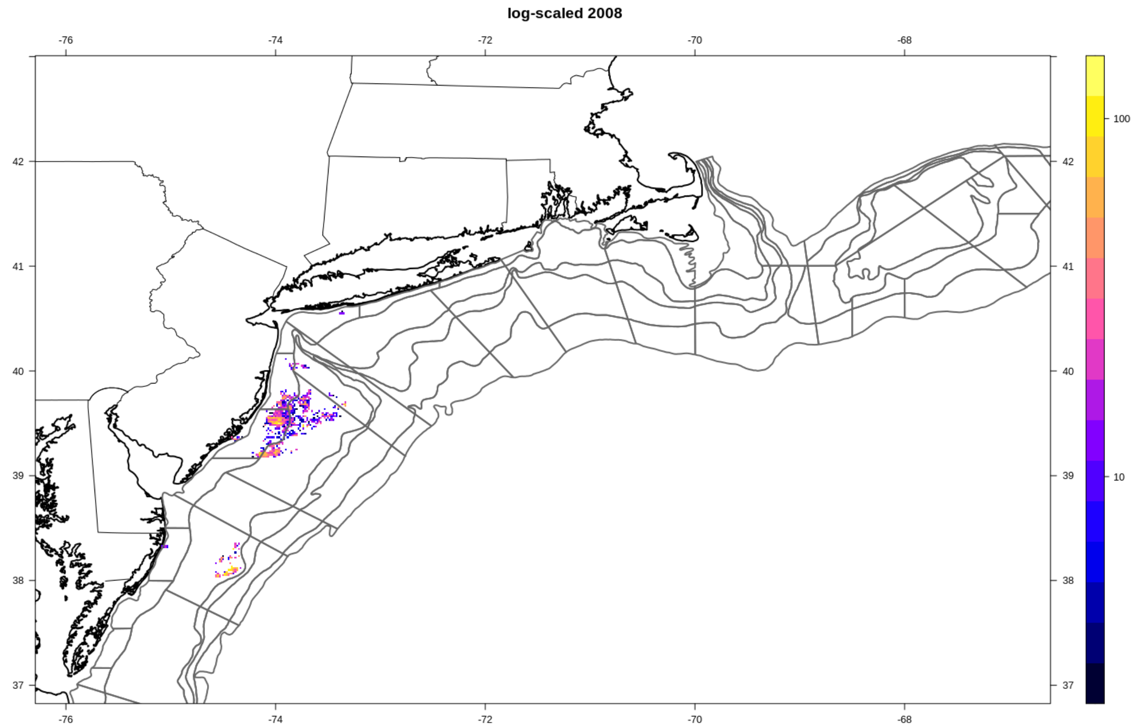



Figure 129: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2008. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2008 are not shown.

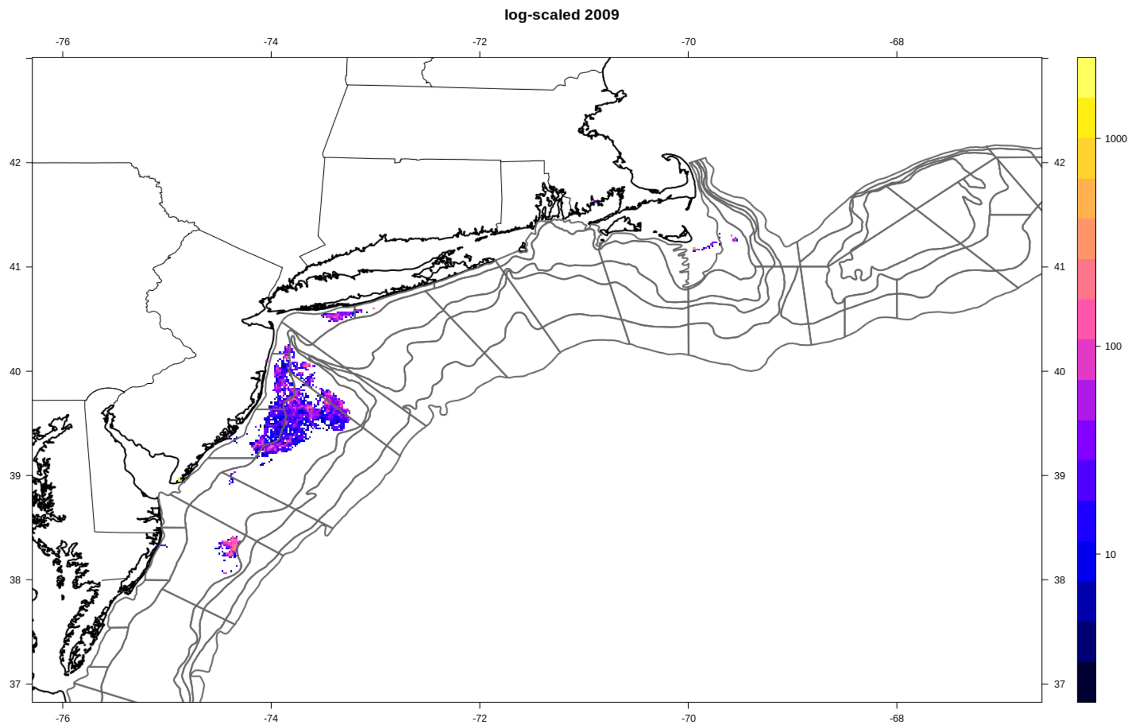



Figure 130: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2009. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2009 are not shown.

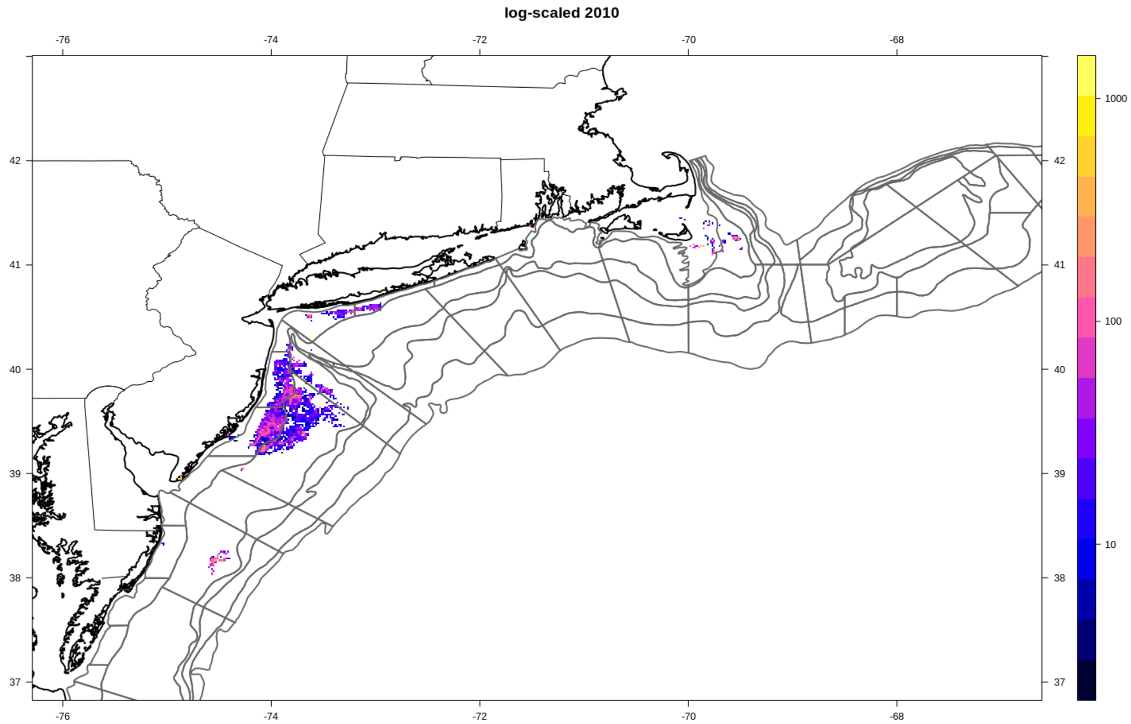



Figure 131: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2010. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2010 are not shown.

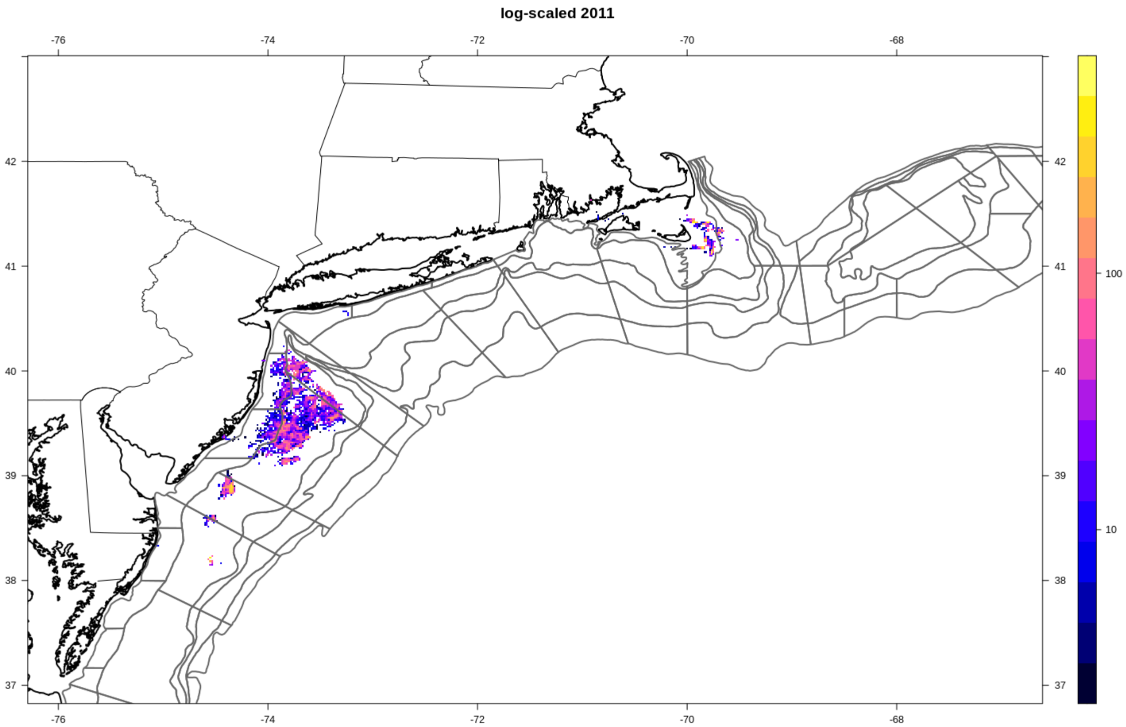



Figure 132: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2011. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2011 are not shown.

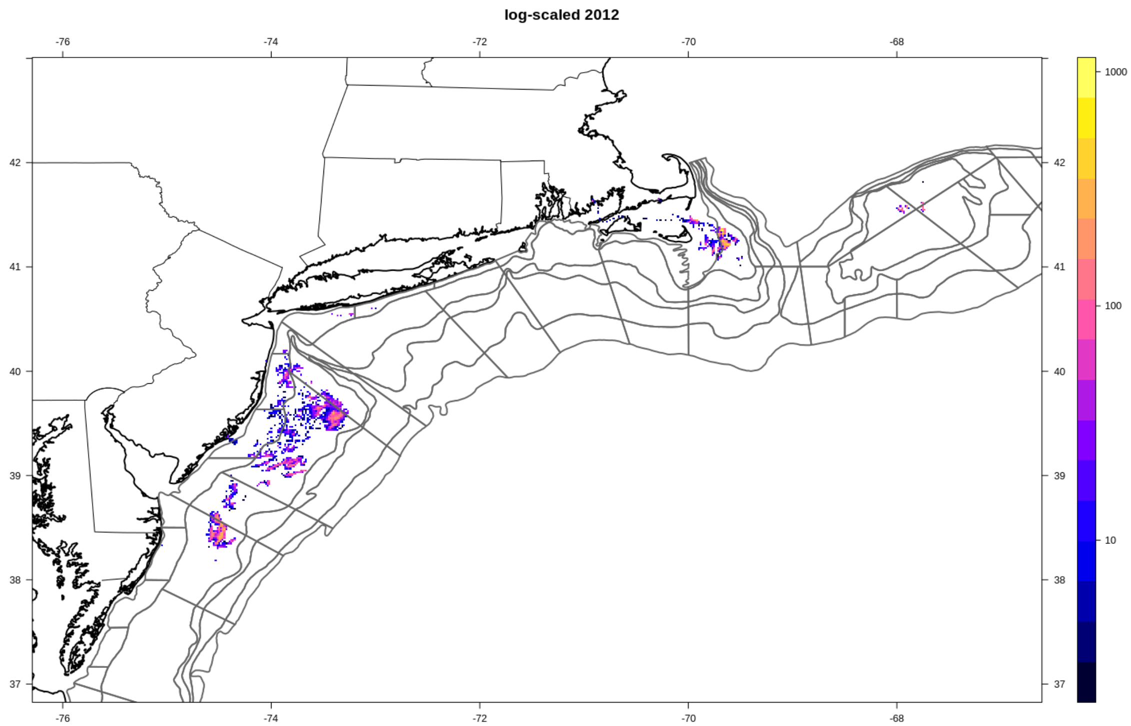



Figure 133: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2012. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2012 are not shown.

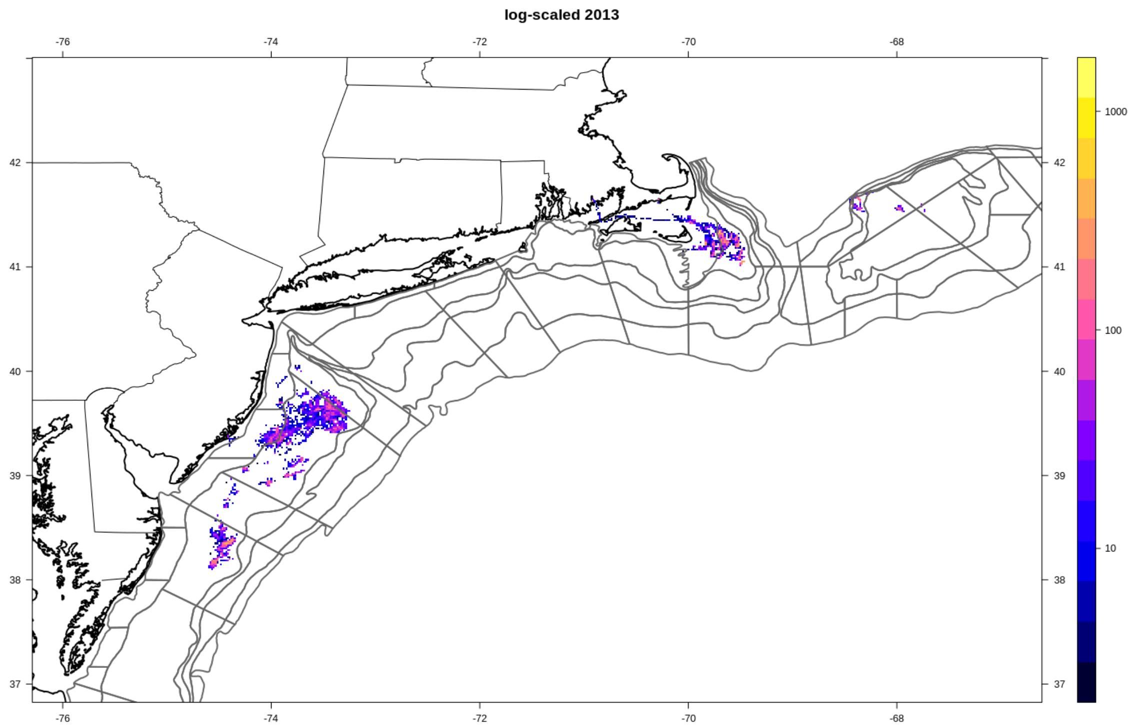



Figure 134: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2013. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2013 are not shown.

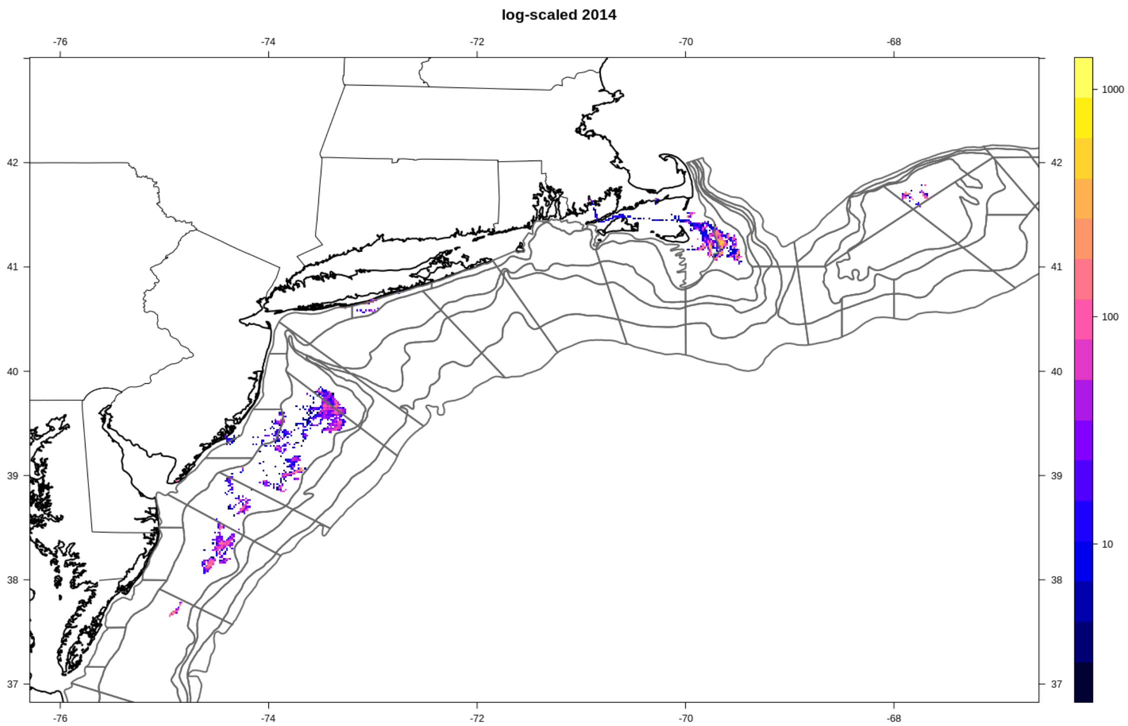



Figure 135: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2014. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2014 are not shown.

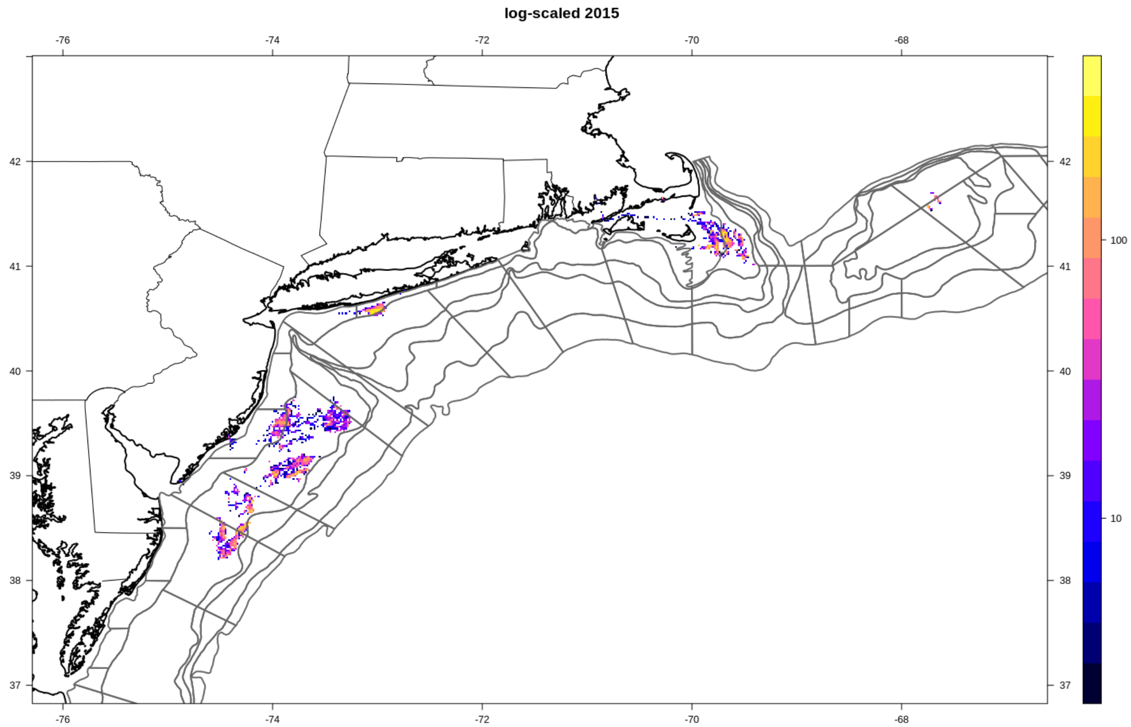



Figure 136: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2015. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2015 are not shown.

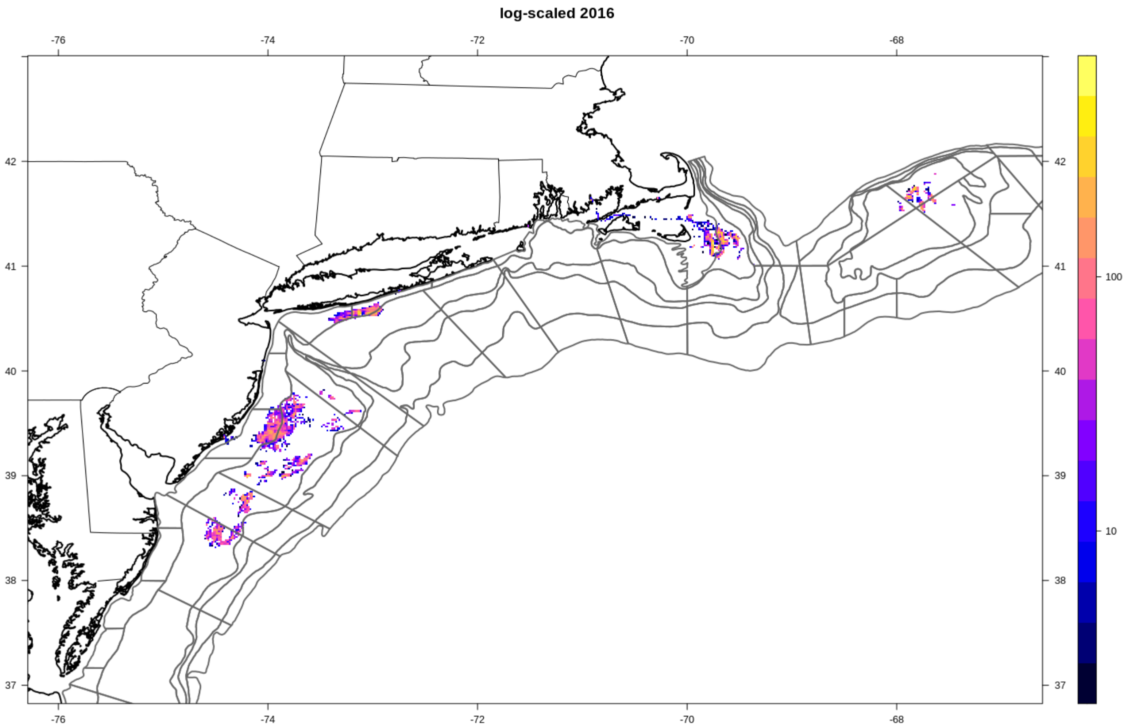



Figure 137: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2016. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2016 are not shown.

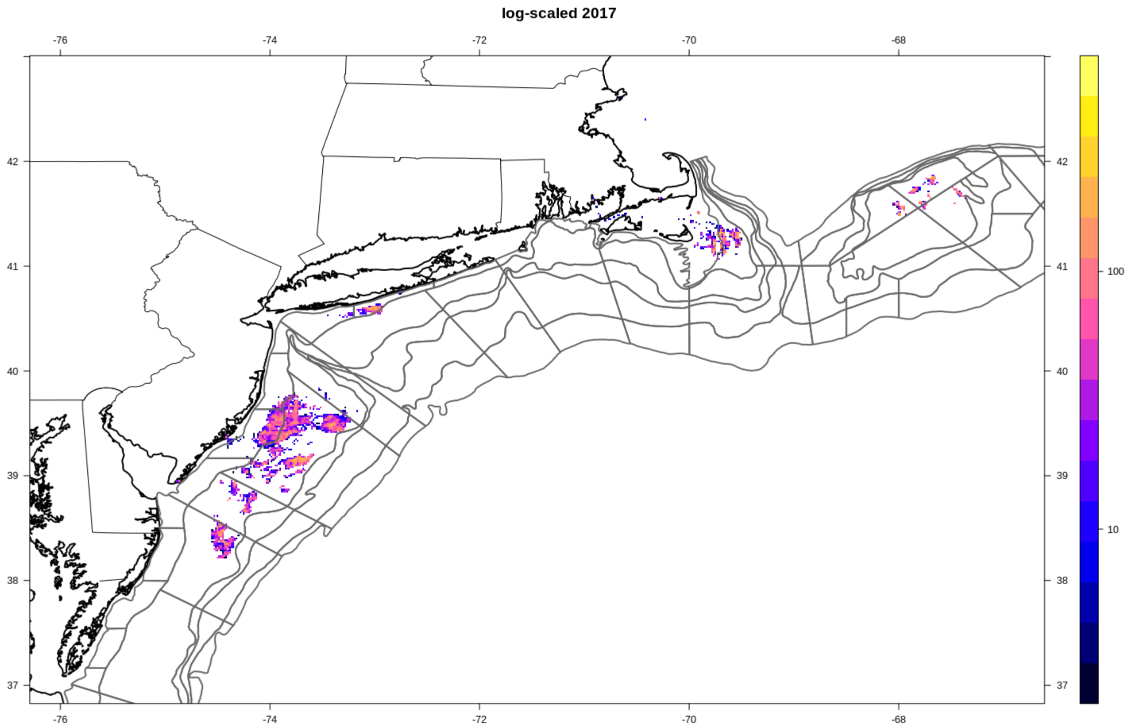



Figure 138: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2017. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2017 are not shown.

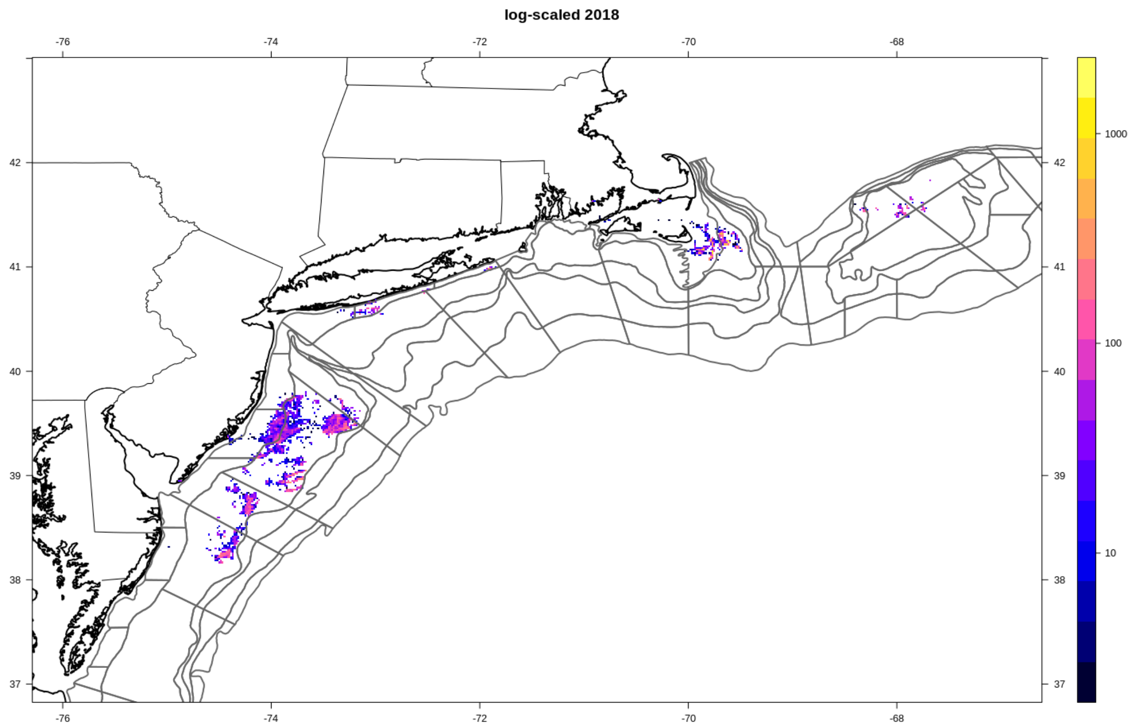



Figure 139: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2018. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2018 are not shown.

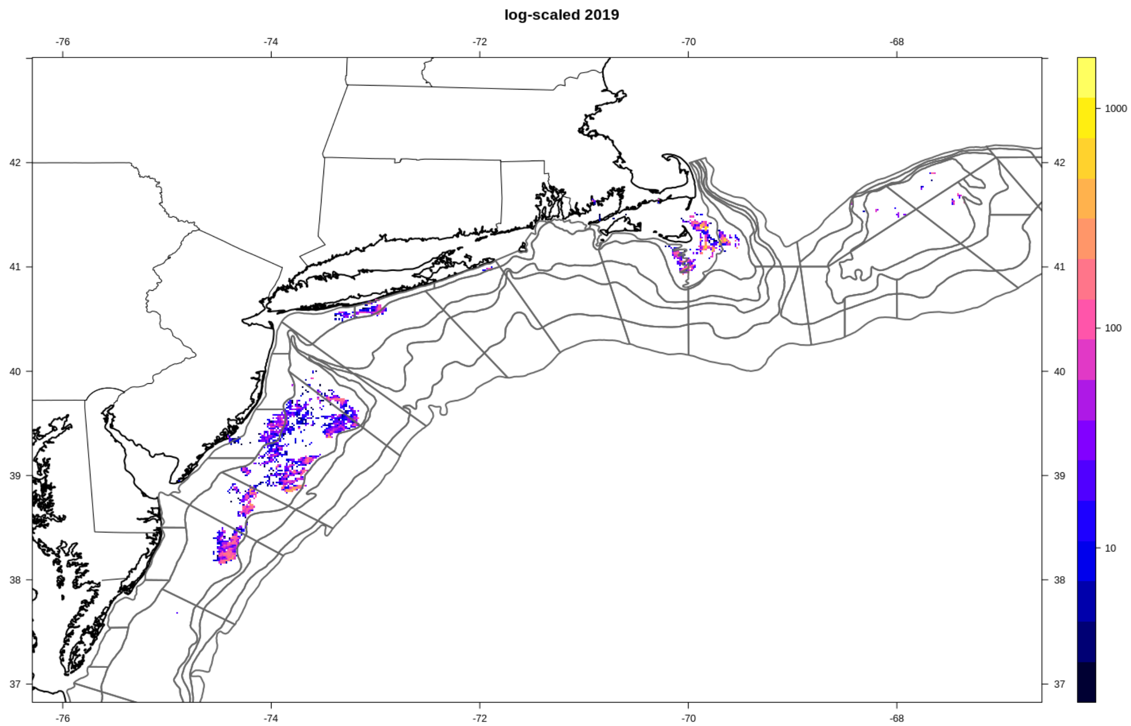



Figure 140: Locations of VMS compliant vessels fishing for Atlantic surfclam in 2019. Locations reflect probable fishing effort based on vessel speed. Locations (1 nm square) where less than 4 boats operated within 2019 are not shown.

# Appendix 2 Restratification of the NEFSC Clam Survey and the NEFSC Clam Database: Atlantic surfclam

The NEFSC clam survey was restratified in 2018 (Jacobson and Hennen 2019) and the survey was deployed using the new strata in that same year. Survey data from years prior to 2018 required post-stratification to comply with the new stratification scheme. Existing automation uses the ClamDataBase originally designed and implemented in SAS. Post stratification was achieved using ClamDataBase. This document provides a description of the testing done to insure that ClamDataBase was correctly modified and that assessment inputs will be correctly calculated.

Post stratification of existing survey data reduced the total number of survey stations considerably. It did not however reduce the observed density of clams. That is, while the number of stations was reduced, most of the stations removed were those were no clams were caught (Table 31). Many of the excluded sites are inshore of the current strata (Figure 141).

Restratification greatly reduced the number of strata. One consequence of this is that there are fewer missed strata in each survey. This reduces the need for imputation of missing data, though missing strata remain a concern for the Atlantic surfclam assessment (Table 32).

Survey indices from the previous and current strata are not directly comparable because the assessment uses an absolute abundance index based on a simple swept area expansion. The current strata cover less area and the expansion factor is therefore less. Because the post stratified tows preserve the majority of observed clams, the average density in tows is higher. These factors balance to some degree, but the survey indices are difficult to compare directly as many factors that go into calculating them were changed by the re-stratification. The relative abundance between years should be similar however, and examination of the previous and current survey indices at length show similar trends through time (Figures 142-143). Trends at length were also similar (Figures 144-146).

Because the stations excluded by post stratification did not represent very much of the total catch, length composition by year and region were not expected to change very much. There were some very minor differences in length composition caused by post stratification, but overall the composition inputs to the assessment should be very similar (Figures 148-149). In fact, the only deviation from identical length compostion occurred in the 1982 GBK area and is due to the changed definitions of that area (Jacobson and Hennen 2019).

Table 31: Comparison of Atlantic surfclam survey data from years prior to 2018 using previous and current stratification. Many tows are dropped under the new stratification, but these represent only a small proportion of the total biomass and abundance caught on the survey.

| Comparison | Old | New | % Difference |
|---|---|---|---|
| Tows | 5019.0 | 2694.0 | 46.3 |
| Total Weight (kg) | 37998.3 | 37660.1 | 0.9 |
| Total abundance (n) | 1450469.0 | 1427946.0 | 1.6 |

Table 32: Number of successful random tows in NEFSC clam surveys used for survey trends and efficiency corrected swept area biomass. 'Holes' (unsampled survey strata in some years) were filled by borrowing from adjacent surveys were possible (borrowed totals are negative numbers in gray shaded boxes). Holes that could not be filled have zeros in black boxes. Survey strata are grouped by region. In 2012 and later the NEFSC survey was conducted from a commercial platform using different gear, and tows were not borrowed across gear types. Starting in 2012, not all regions were sampled in each survey year. Instead the survey was conducted in either the northern or southern area. Areas intentionally not sampled are left blank in those years. 2014 was not intended to be a survey year, but some strata were sampled in order to fill holes left over from 2013. 6S was surveyed in 2013, but the survey results were borowed to 2012 and not used in 2013. The NEFSC clam survey was restratified in 2018 and strata that were surveyed off cycle (e.g. 3S in 2014) were surveyed under the previous stratification.

| Strata | 1982 | 1983 | 1984 | 1986 | 1989 | 1992 | 1994 | 1997 | 1999 | 2002 | 2005 | 2008 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | **SVAtoSNE** | | | | | | | | | | |
| 1S | 34 | 39 | 55 | 40 | 50 | 50 | 51 | 52 | 38 | 52 | 44 | 31 | 24 | 17 | | | 15 | | 9 | |
| 2S | 20 | 17 | 20 | 21 | 21 | 20 | 21 | 21 | 19 | 28 | 18 | 21 | 20 | 29 | | | 12 | | 9 | |
| 3S | 65 | 66 | 76 | 69 | 71 | 71 | 75 | 84 | 88 | 80 | 69 | 84 | 45 | 28 | | | 43 | | 118 | |
| 4S | 10 | 10 | 5 | 12 | 12 | 12 | 16 | 12 | 12 | 12 | 12 | 8 | 37 | 17 | | | 18 | | 11 | |
| 5S | 36 | 37 | 57 | 41 | 46 | 45 | 44 | 48 | 49 | 47 | 40 | 52 | 42 | 30 | | | 53 | | 23 | |
| 6S | 9 | 38 | 25 | 12 | 11 | 14 | 15 | 15 | 11 | 9 | 6 | 12 | 18 | -14 | 14 | 2 | 5 | 8 | 8 | |
| | | | | | | | | | | **GBK** | | | | | | | | | | |
| 7S | 1 | -4 | 3 | 3 | -6 | 3 | 3 | 3 | -3 | 0 | -2 | 2 | 2 | | -5 | 5 | | 8 | | 10 |
| 8S | 3 | 7 | 5 | 15 | 13 | 17 | 18 | 17 | 10 | 2 | -12 | 10 | 21 | | 12 | 9 | | 34 | | 57 |
| 9S | 1 | 3 | -7 | 4 | 5 | 8 | 11 | 8 | 7 | 7 | -14 | 7 | 28 | | 33 | | | 25 | | 23 |
| 10S | 2 | -2 | -2 | 2 | -4 | 2 | 4 | 3 | -4 | 1 | -1 | -3 | 3 | | 4 | | | 8 | | 9 |
| 11S | 4 | 1 | 15 | 6 | 20 | 19 | 19 | 19 | 11 | 5 | -18 | 13 | 9 | | 10 | 5 | | 31 | | 60 |
| 12S | 3 | -5 | 2 | 7 | 1 | 6 | 7 | 7 | 4 | 6 | -10 | 4 | 15 | | 9 | | | 19 | | 22 |

Figure 141: Map showing the new strata and all NEFSC clam survey stations. The stations have been color coded to conform to the new strata. Stations in black are not in the new strata.

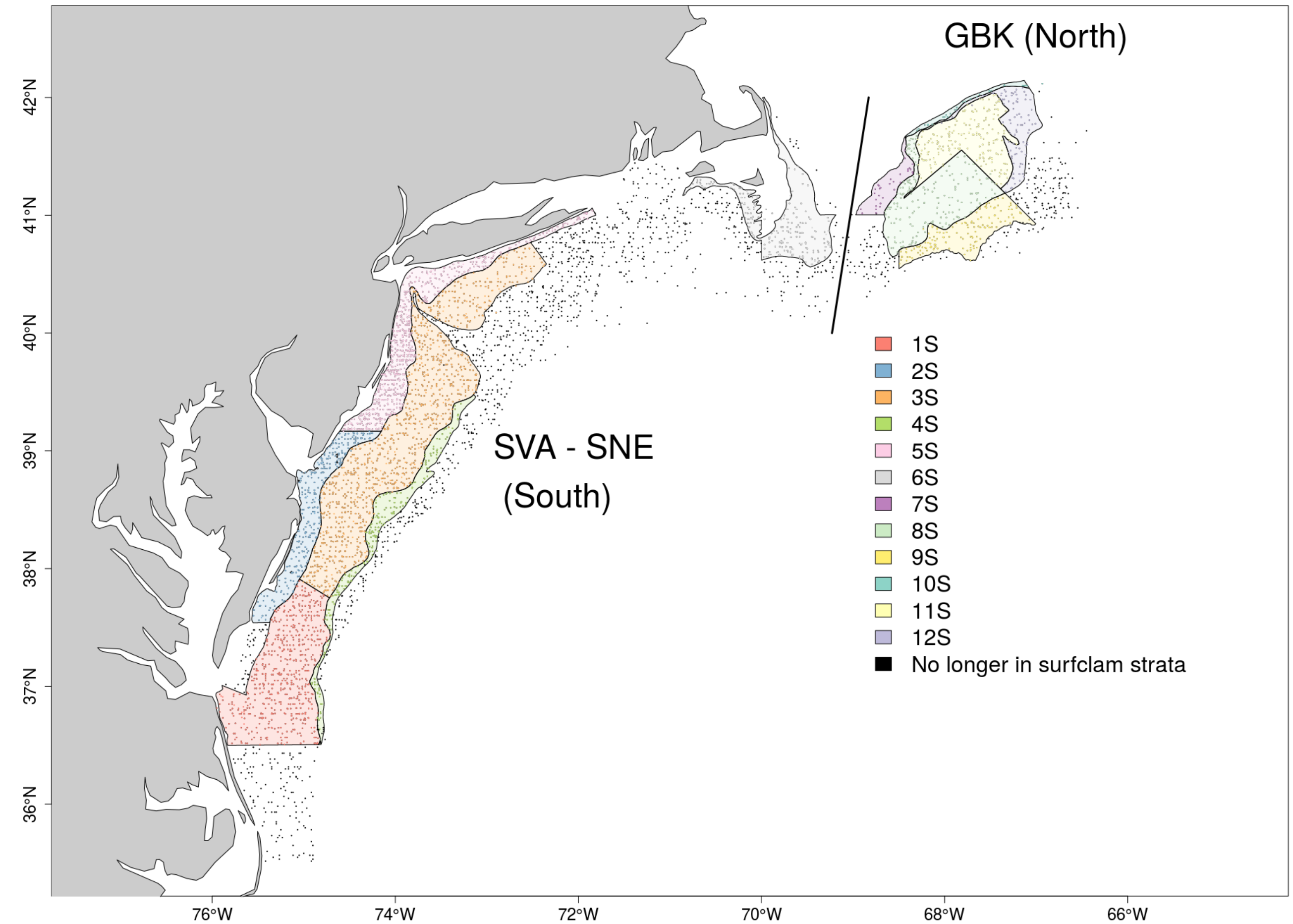


Figure 142: Survey indices from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey.

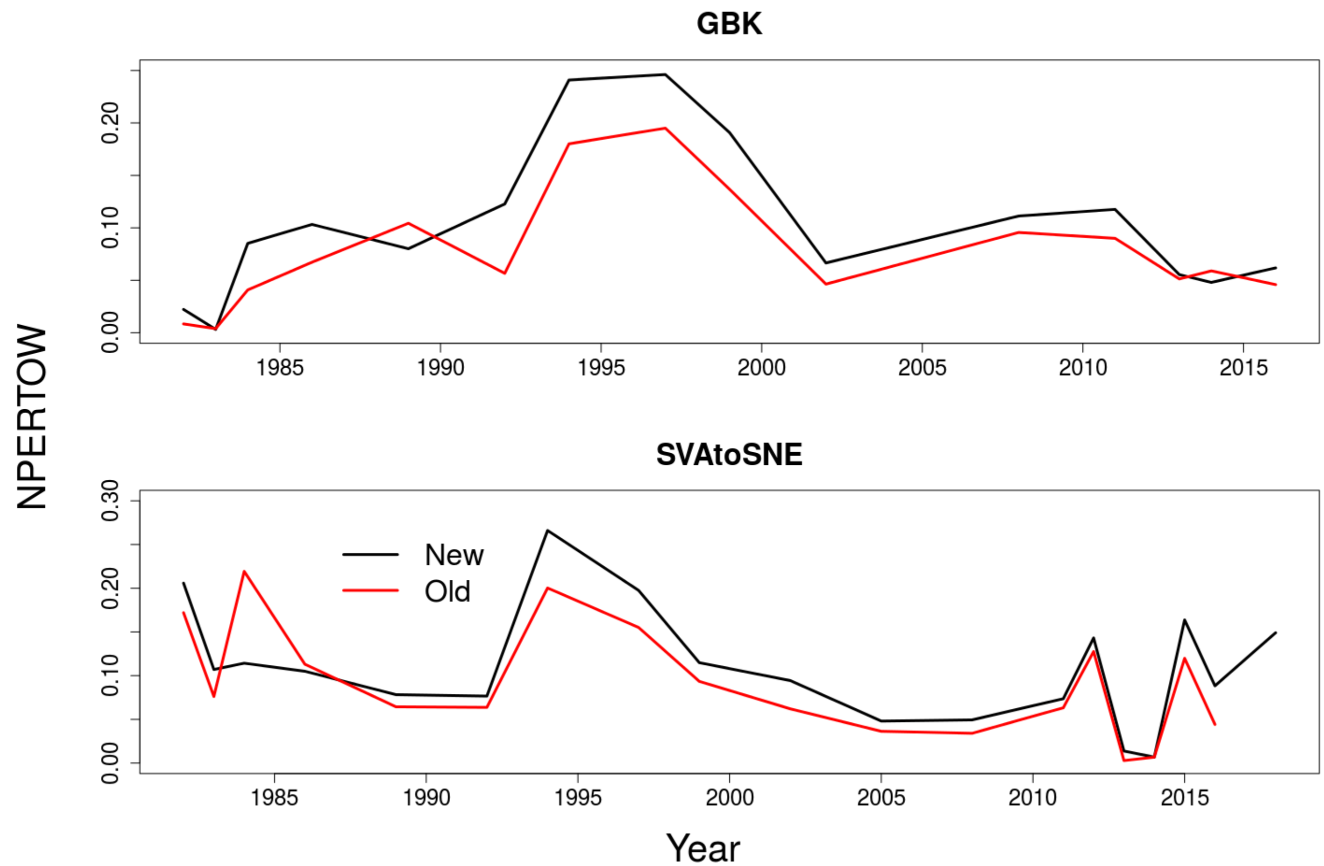


Figure 143: Survey indices from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey.

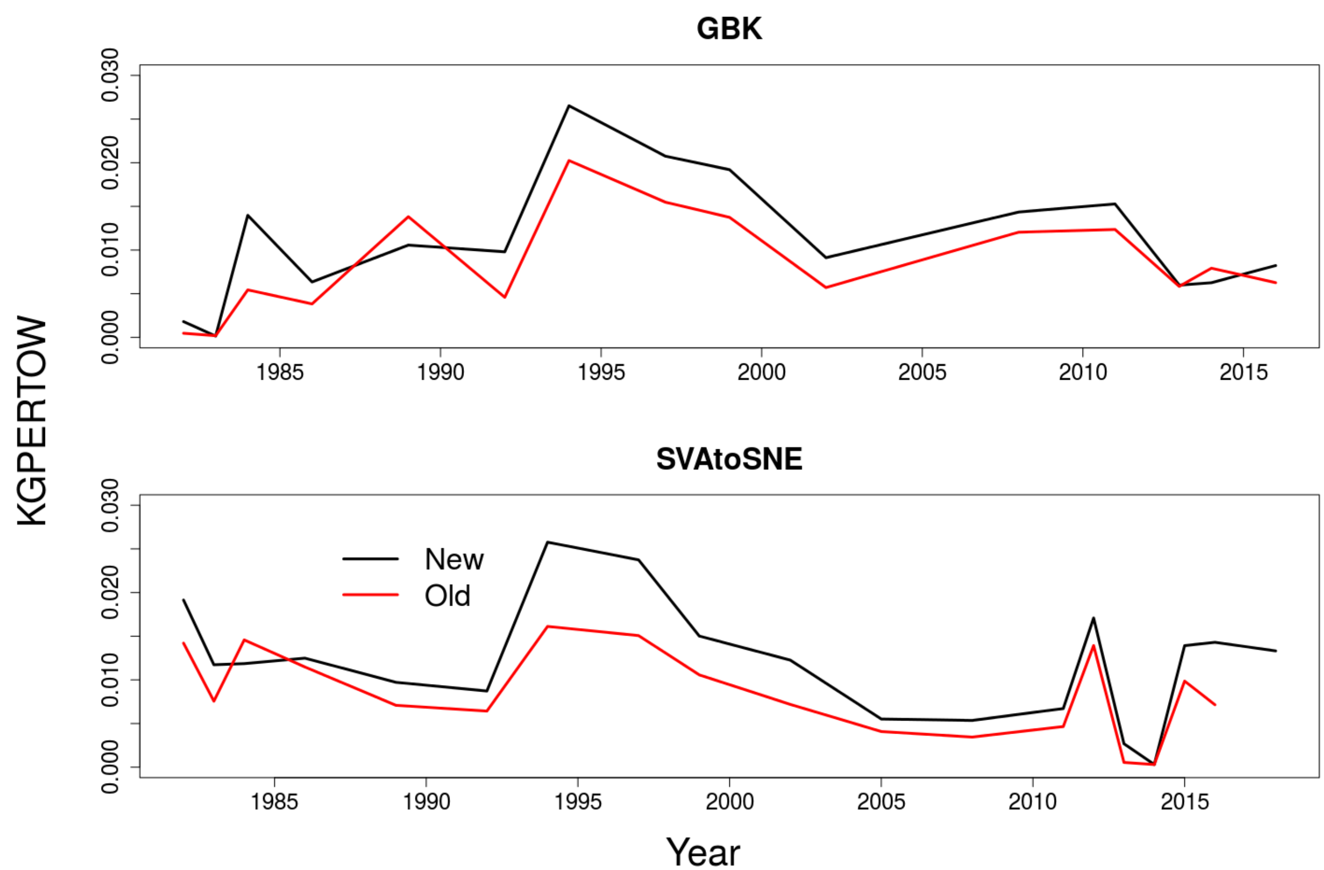


Figure 144: Survey indices at length from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey of GBK.

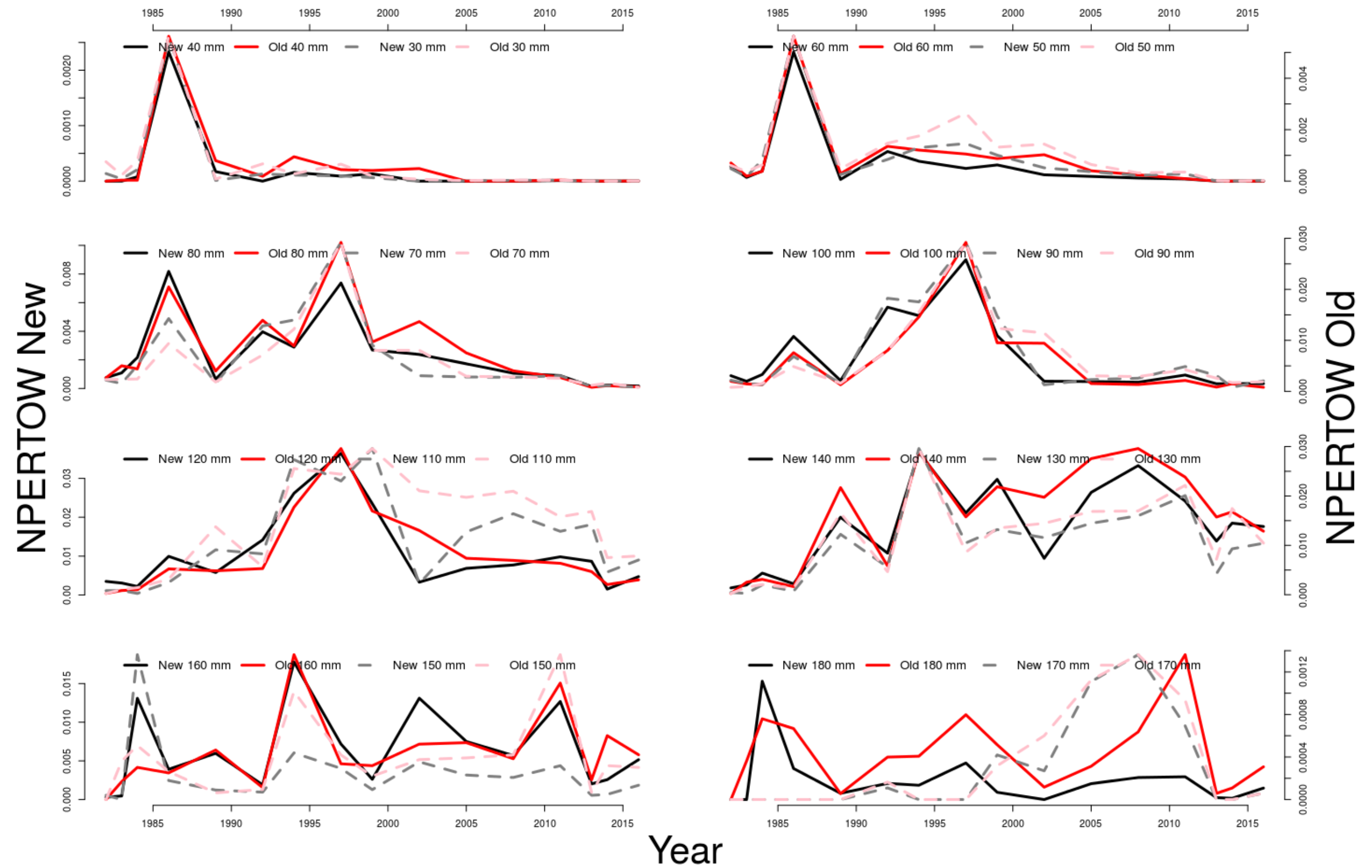


Figure 145: Survey indices at length from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey of GBK.

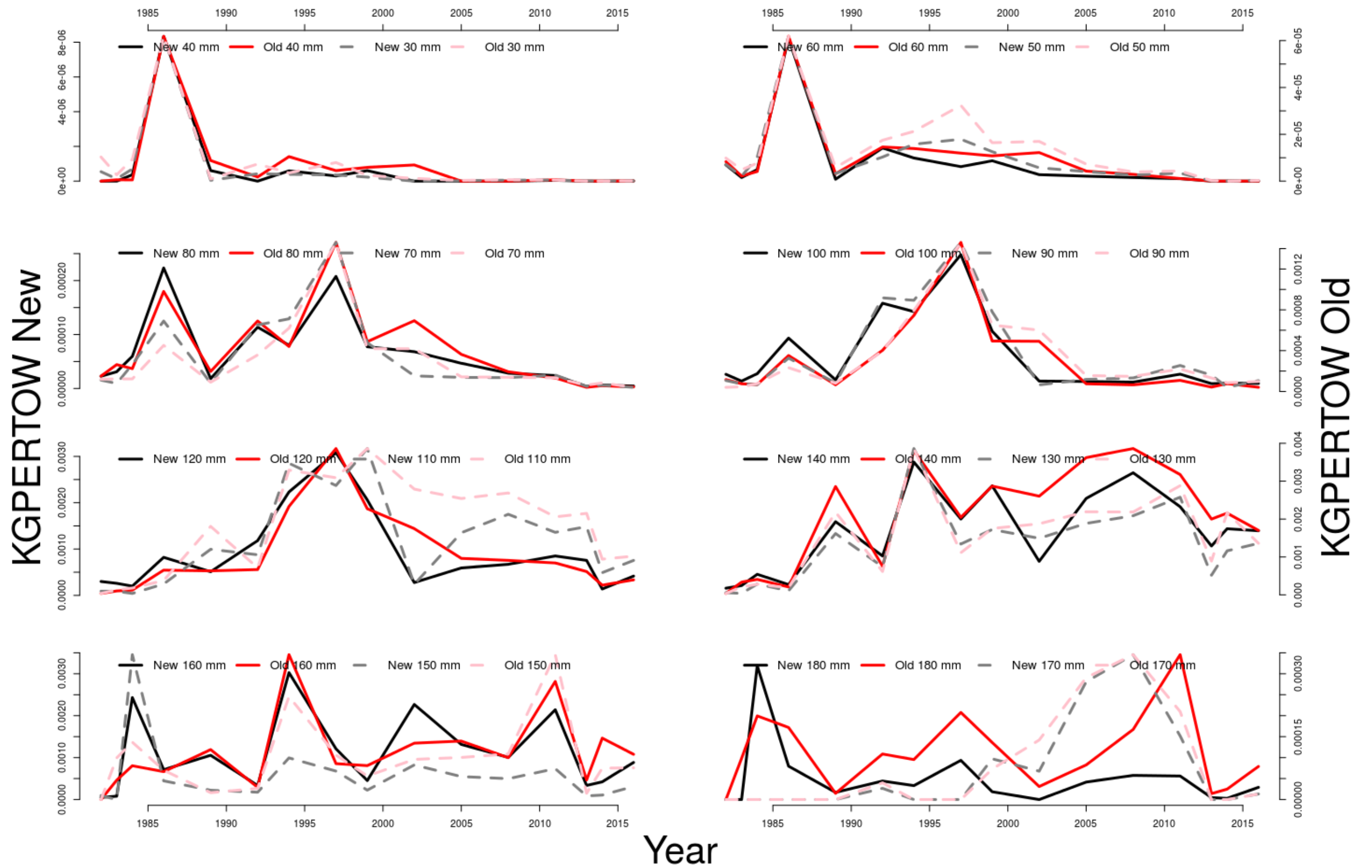


Figure 146: Survey indices at length from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey of SVA to SNE.

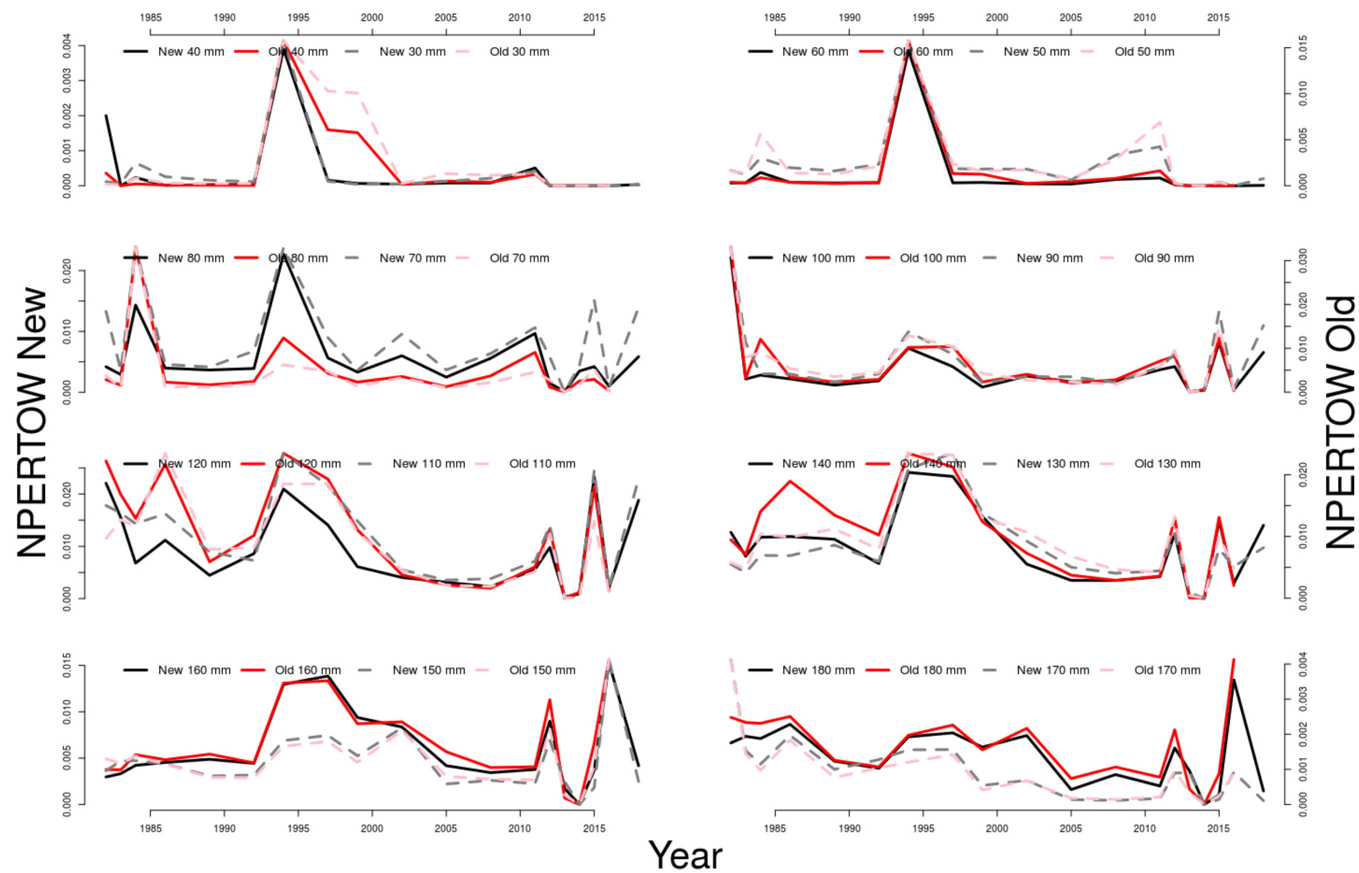


Figure 147: Survey indices at length from the NEFSC clam survey pre and post the change to a new stratification scheme from the NEFSC clam survey of SVA to SNE.

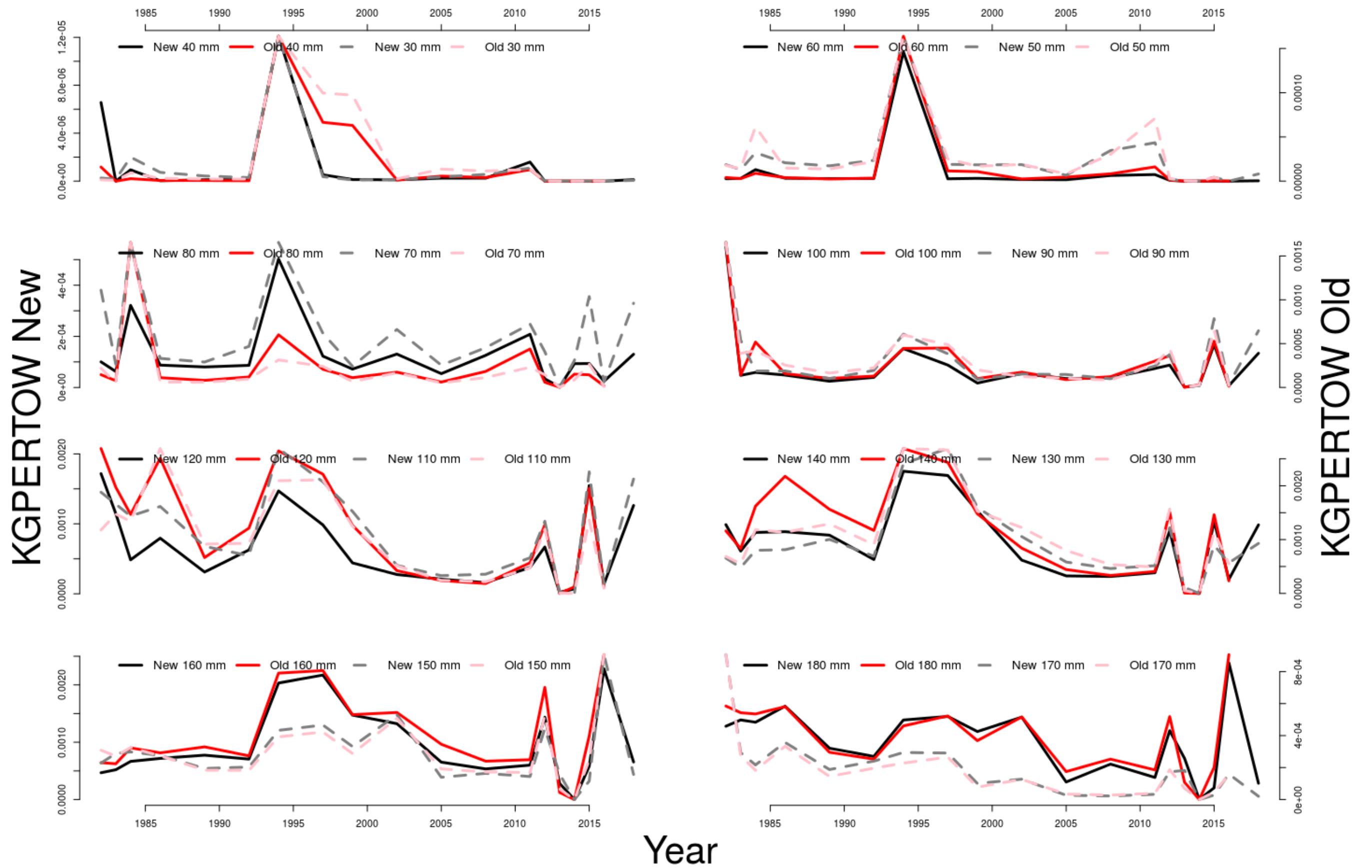


Figure 148: Length composition data from the NEFSC clam survey pre and post the change to a new stratification scheme from GBK. The length compositions based on the new strata are in red.

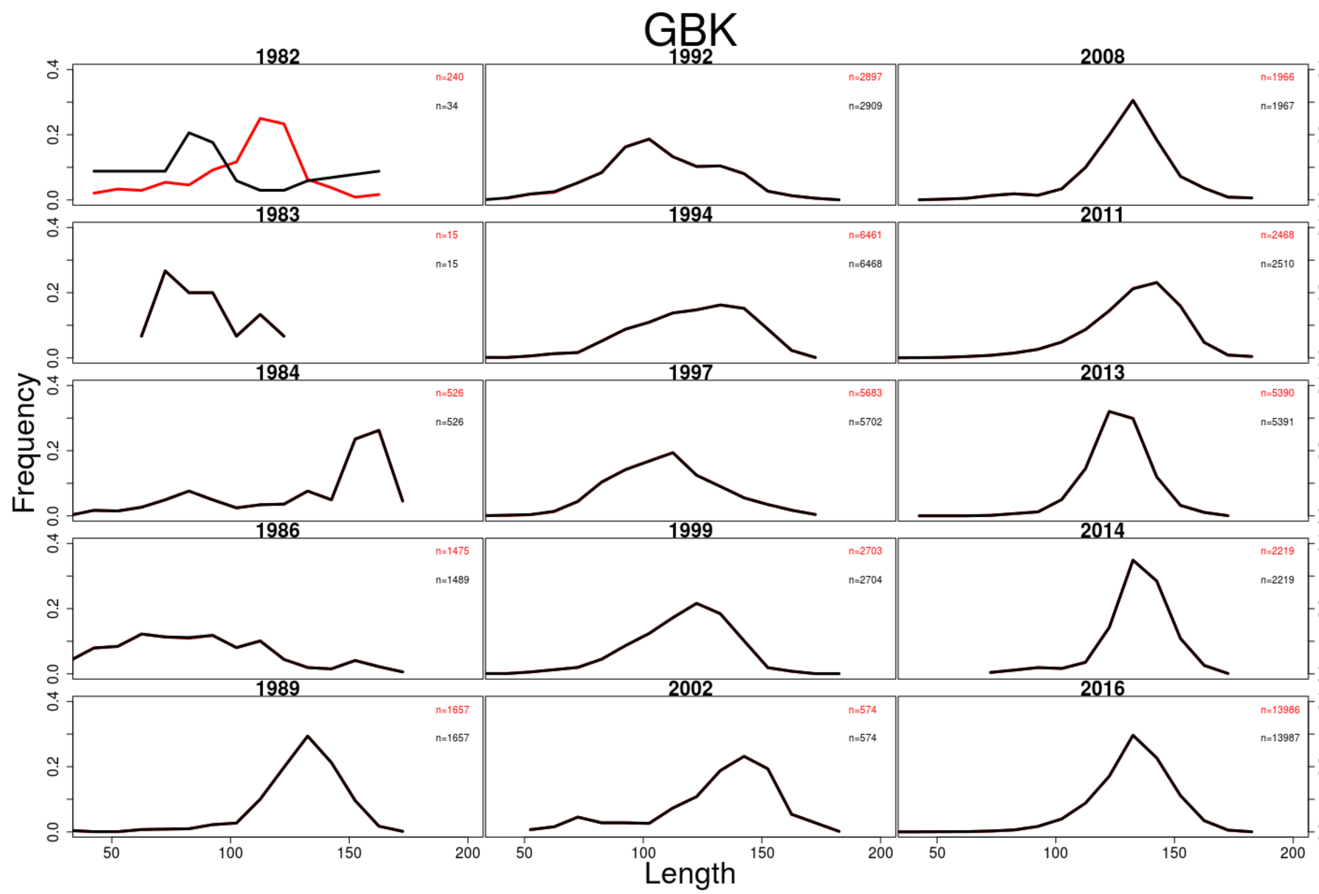
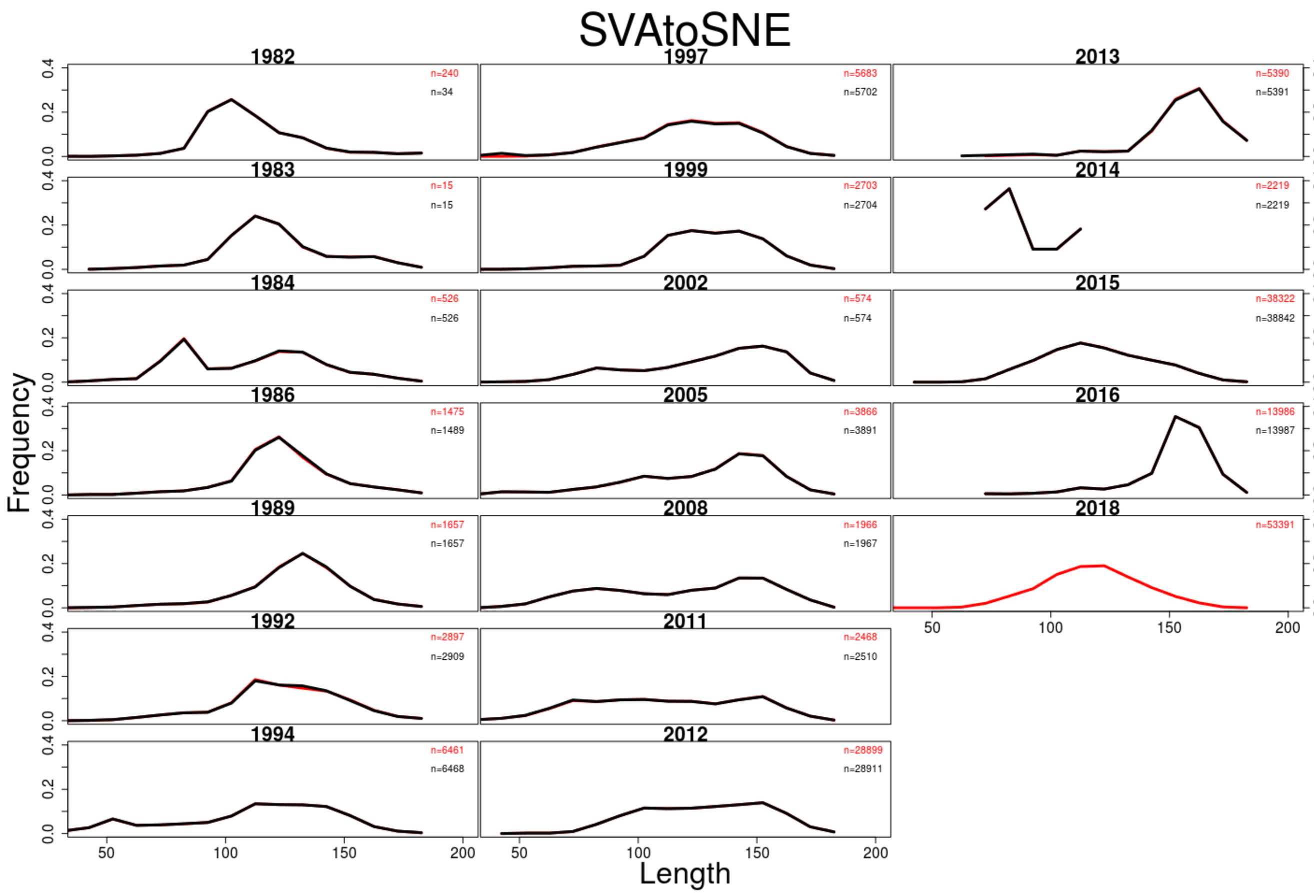


Figure 149: Length composition data from the NEFSC clam survey pre and post the change to a new stratification scheme from the southern area. The length compositions based on the new strata are in red.



## Appendix 3 Survey dredge efficiency

Increasing survey dredge efficiency, defined as the probability of capturing an animal if the dredge is towed over the bottom where that animal is buried, was an important consideration in switching to a commercial vessel as a platform for the NEFSC clam survey. The relatively small survey dredge deployed by the *RV Delaware II* had an estimated mean efficiency of approximately 0.23 and high variability in performance, with an estimated cv for efficiency of 1.32. A low mean dredge efficiency coupled with high variability resulted in high variance catches, which in turn increased the variability in estimates of mean abundance for survey strata, and ultimately for estimated biomass in the assessment.

The complex process for estimating survey dredge efficiency (described in detail in Northeast Fisheries Science Center (2013)) included 27 direct estimates of the efficiency of modified commercial dredges (MCD) similar to those that have been used in the NEFSC clam survey since 2012, including 8 estimates using the actual MCD used for the post-2012 surveys (Table 33). The efficiency of the MCD and the Pursuit dredge are substantially higher and more precisely estimated than the RD (Figure 164).

The depletion experiments have thus far been conducted in the southern area, with the most effort concentrated in the NJ region (Figure 150)

## Tables

Table 33: Estimated dredge capture efficiency from depletion experiments. All experiments were conducted using a modified commercial dredge similar to, though somewhat smaller than the dredge that has been used for the NEFSC clam survey since 2012. Experiments after 2007 were conducted using the same dredge used in the survey.

| Experiment | Efficiency | St. dev. |
|---|---|---|
| 1997.2 | 0.224 | 0.069 |
| 1997.3 | 0.641 | 0.138 |
| 1997.4 | 0.917 | 0.198 |
| 1997.6 | 0.528 | 0.171 |
| 1999.2 | 0.589 | 0.263 |
| 1999.5 | 0.211 | 0.058 |
| 1999.7 | 0.480 | 0.073 |
| 2002.2 | 0.805 | 0.109 |
| 2002.3 | 0.446 | 0.139 |
| 2004.1 | 0.552 | 0.105 |
| 2004.2 | 0.628 | 0.078 |
| 2004.3 | 0.606 | 0.111 |
| 2005.2 | 0.666 | 0.068 |
| 2005.3 | 0.569 | 0.068 |
| 2005.4 | 0.389 | 0.079 |
| 2005.5 | 0.781 | 0.145 |
| 2005.6 | 0.535 | 0.140 |
| 2008.1 | 0.966 | 0.142 |
| 2008.2 | 0.957 | 0.103 |
| 2008.3 | 0.610 | 0.119 |
| 2008.4 | 0.485 | 0.212 |
| 2008.6 | 0.882 | 0.143 |
| 2011.3 | 0.571 | 0.162 |
| 2011.2 | 0.556 | 0.088 |
| 2011.1 | 0.738 | 0.090 |

## Figures

**Figures**

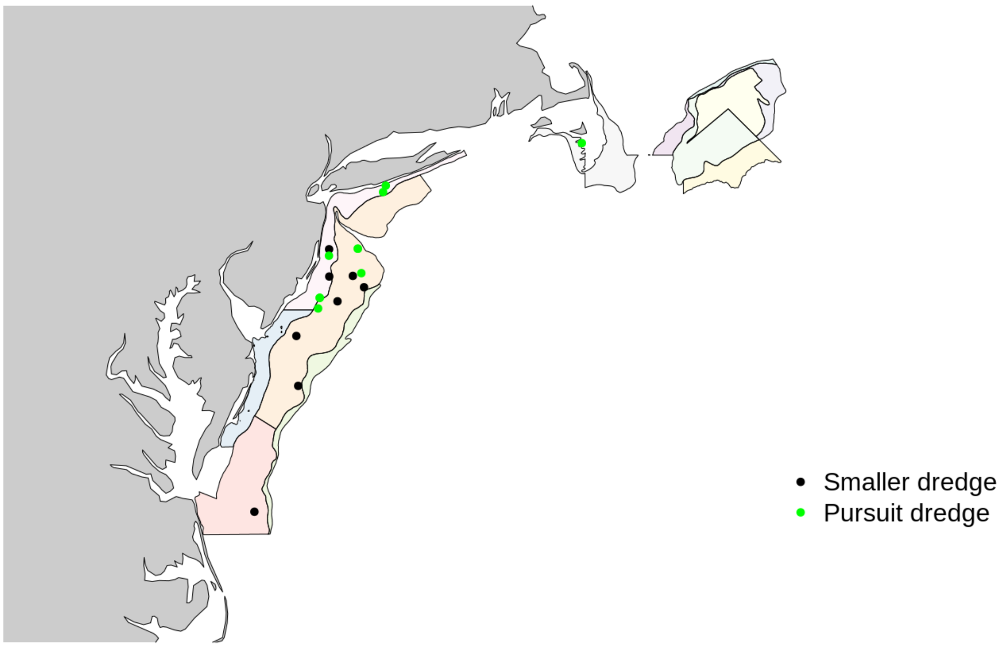



Figure 150: Position of each depletion experiment. The different colors represent the depletion experiments done with different dredges. The green dots are the experiments done with the dredge being used currently on the NEFSC clam survey.

## Appendix 4 Build a bridge

The most substantial change from the previous assessment Northeast Fisheries Science Center (2017a) to this assessment is the shift from two models for two separated areas to one model with two areas. This shift makes direct comparison difficult, but an attempt was made to illustrate the affect of sequential changes on the model(s).

### Southern area

Before shifting to the current spatial model some changes to the data and model framework were applied to the previous model for the southern area. The changes include an update of the model framework to the latest available version of Stock Synthesis (version 3.30.14) at the time of this writing. The model also incorporates post stratified survey due to the restratification of the NEFSC clam survey (Jacobson and Hennen 2019) and explicitly includes discards from recent years, which were previously assumed to be 0. The changes affected the scale but the trend in biomass was relatively stable (Figure 151 - 153).

### Northern area

Before shifting to the current spatial model some changes to the data and model framework were applied to the previous model for the northern area. The changes include an update of the model framework to the latest available version of Stock Synthesis (version 3.30.14) at the time of this writing. The model also incorporates post stratified survey due to the restratification of the NEFSC clam survey (Jacobson and Hennen 2019). The model also explicitly incorporated discards which were previously assumed to be 0. The changes affected both the trend and scale of the northern area estimates of biomass and $F$. In general the previous perception of the stock may have been optimistic as the current model indicates a higher unfished level and lower terminal estimate of biomass (Figure 151 - 153). The change in perception appears to be a result of the restratification, which was undertaken largely as a means of improving the survey for the northern area.

### Whole stock

The two area model for the whole stock developed for this assessment initially estimated all of the same parameters as the two models used previously. New data was incorporated at this stage that included three additional years of commercial data and the resulting length composition, as well as one additional survey year in the south and two additional survey years in the north. Survey data included length composition and age at length data. Shifting to an area model caused a shift in scale (see Figure 117, but it should be noted that scale was highly uncertain in the previous assessment and shifts in scale were common in sensitivity runs. Uncertainty in scale was the justification for the use of trend based reference points in the last assessment and shifting scale should be problematic for management.

A sequence of changes to the initial area model followed. In general the changes were motivated by poor model diagnostics and the fact that more data and an improved model structure helped inform the estimation of parameters that were fixed previously to improve model convergence (Figures 157 - 159).

A relatively poor fit to the length composition data from the commercial fishery in the north led to the estimation of growth parameters in the north. A relatively poor fit to the length composition from the RDtrend survey in both areas motivated allowing the model to estimate selectivity for that survey in both areas, while additional data motivated the estimation of selectivity for the MCD survey in both areas.

An anomalous spike at a size below that selected for in the fishery in the commercial length composition data for both areas led to the removal of those data.

Continued poor fit to some years of the RDtrend and commercial length composition data in the south motivated the estimation of time varying growth parameters there (discussed in more detail in section 1.4).

Some of the selectivity parameters were poorly determined and these were constrained through the use of prior distributions, essentially adding a penalty to help the model with convergence and gradient issues.

Finally changing the F report basis (a mistake in the input files was corrected) had no affect on the model fit, but is reported here because it appears to affect the estimation of F.

### Figures

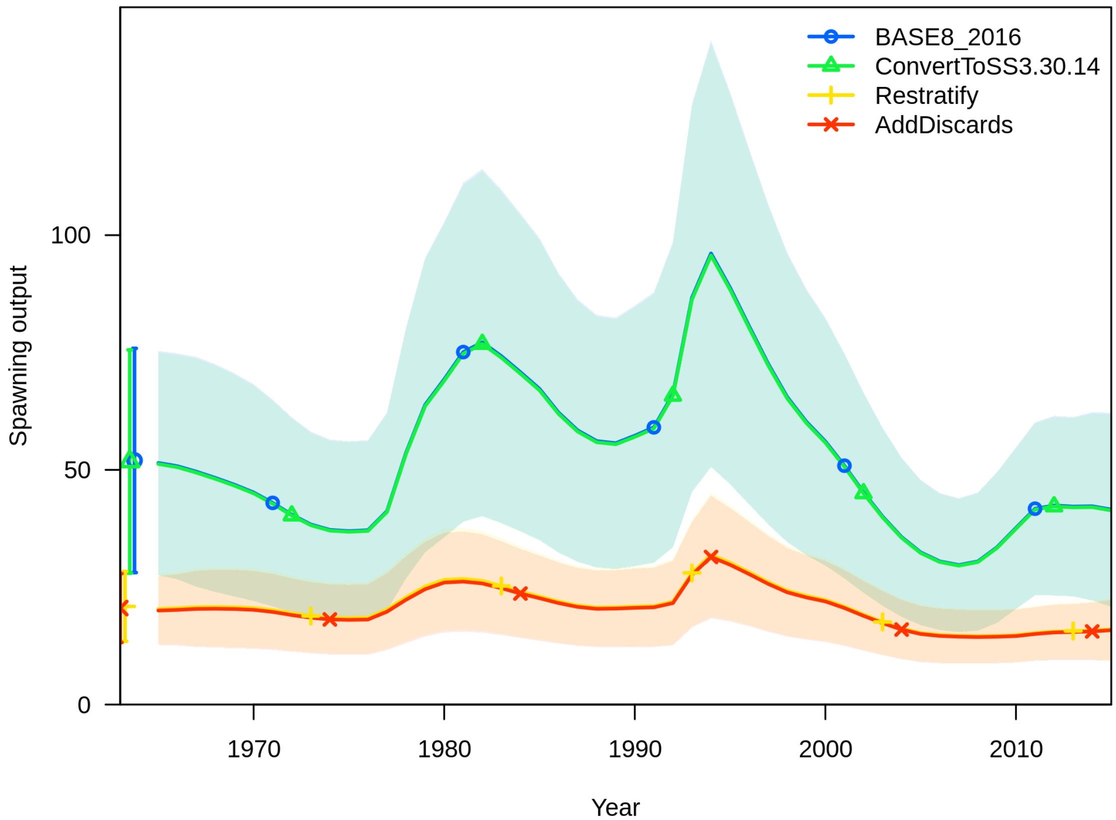



Figure 151: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

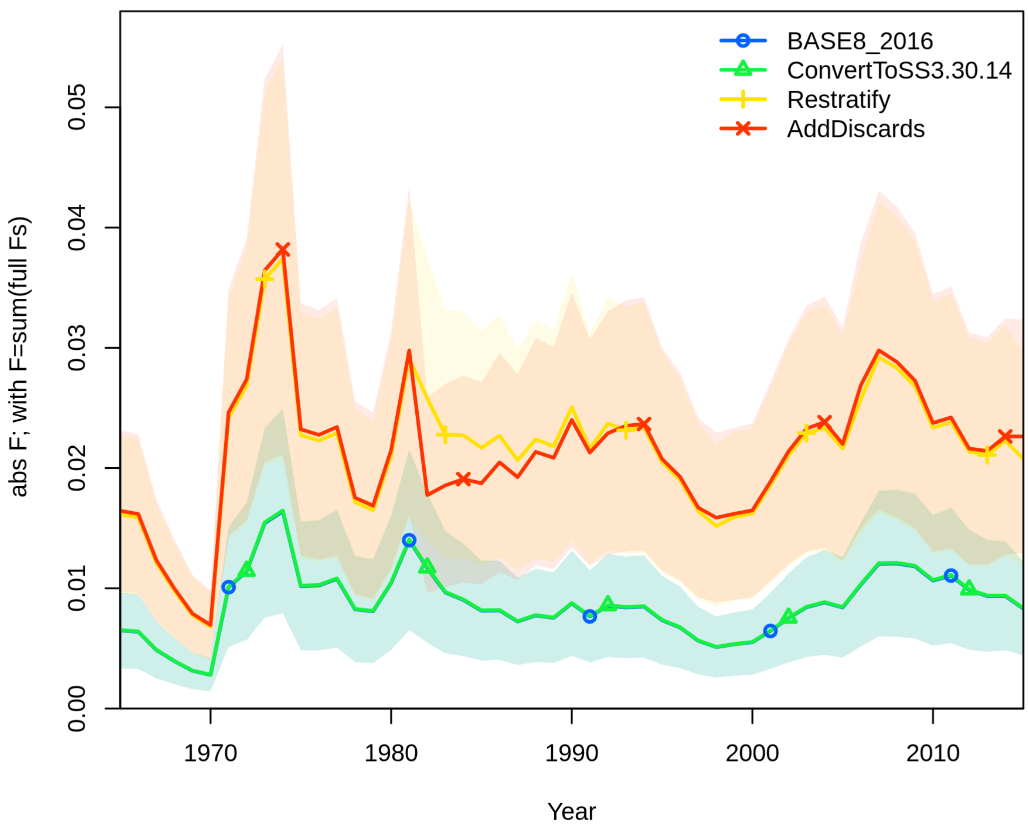



Figure 152: A comparison of the fishing mortality trajectories from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

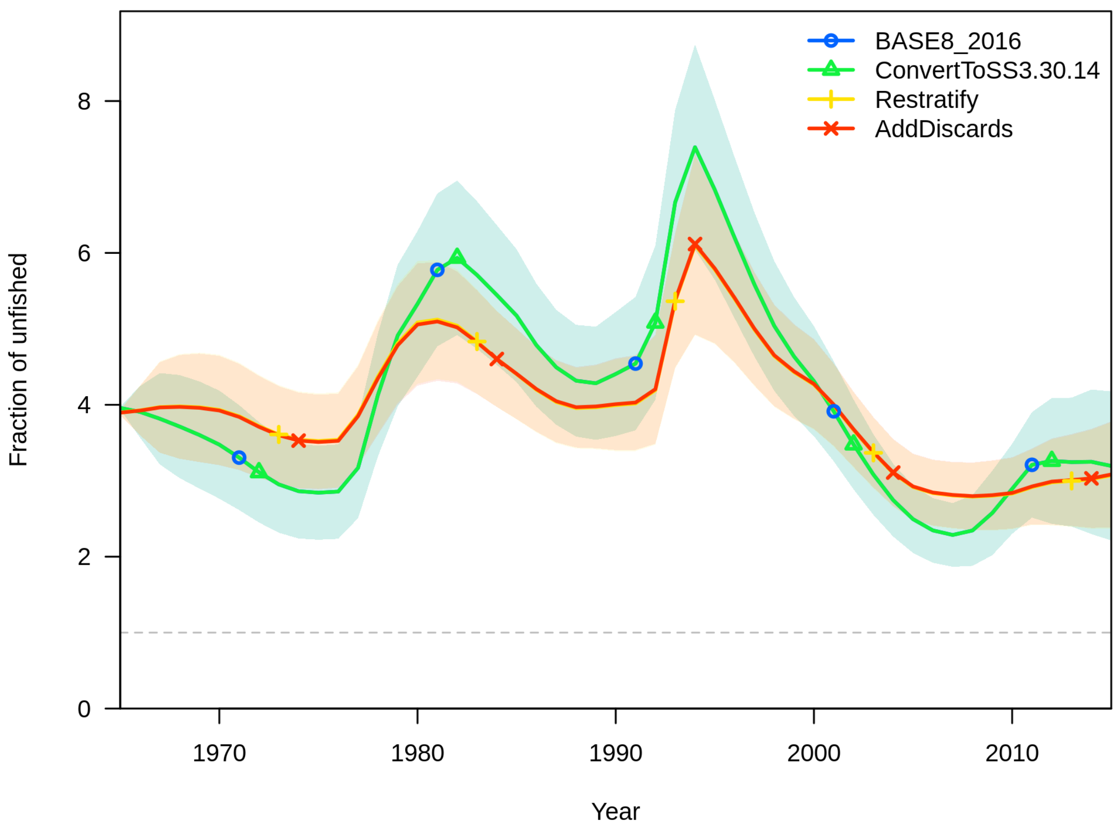



Figure 153: A comparison of the spawning output trajectories relative to initial spawning output estimates from each model (removing scale) from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

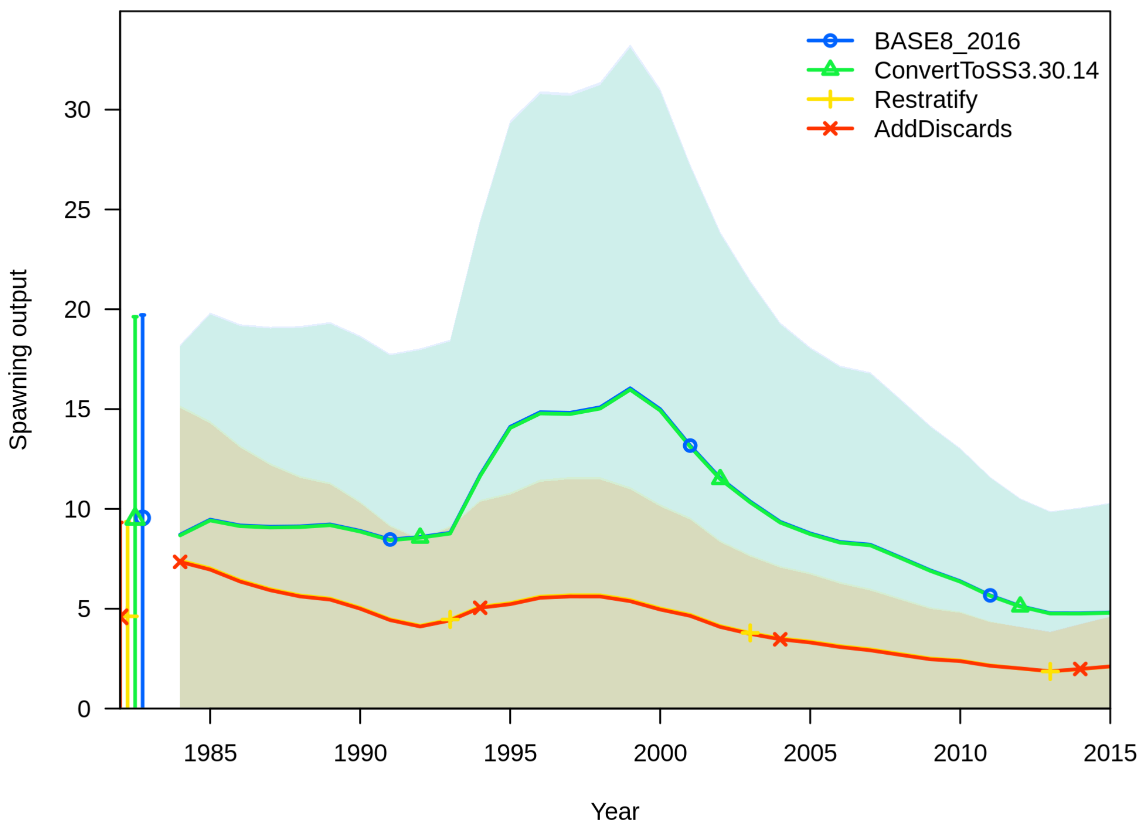



Figure 154: A comparison of the spawning output trajectories from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

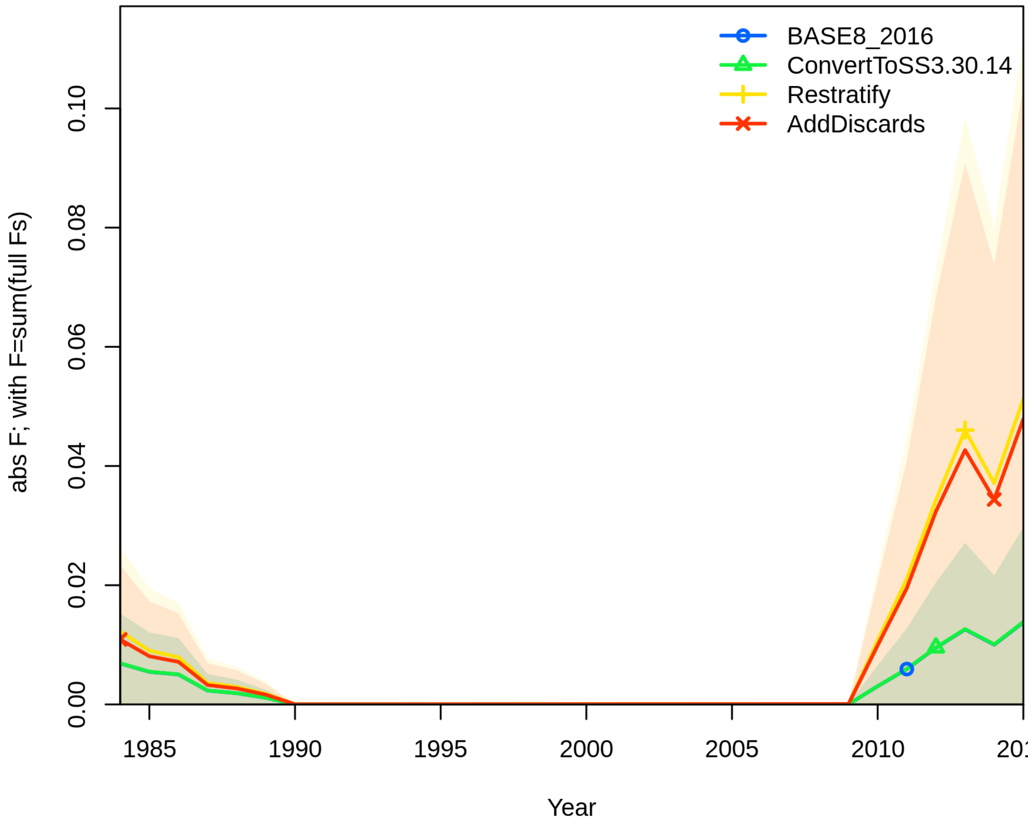



Figure 155: A comparison of the fishing mortality trajectories from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

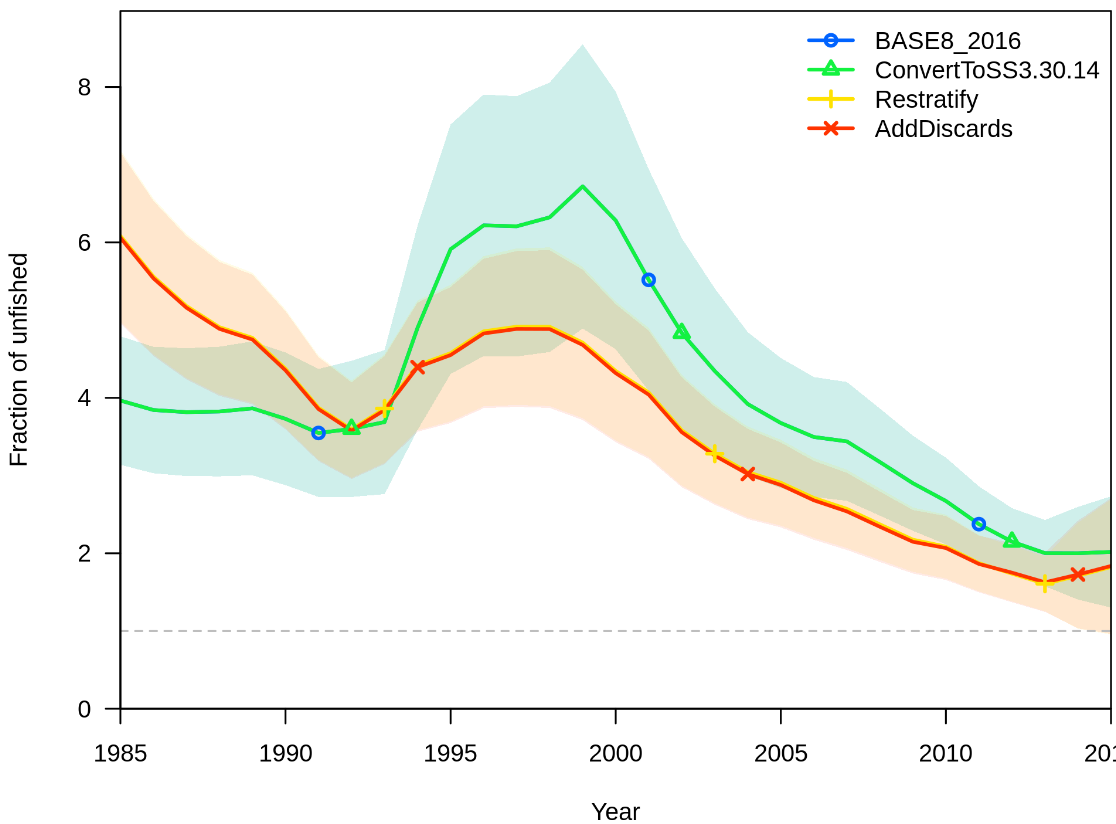



Figure 156: A comparison of the spawning output trajectories relative to initial spawning output estimates from each model (removing scale) from the final model for the southern area from the last assessment (BASE8_2016) to models incorporating several changes to the data and structure of the model. The changes included converting to the latest version of SS (ConvertToSS3.30.14), restratifying the survey data (Restratify), and explicitly including discards in the calculation of catch (AddDiscards).

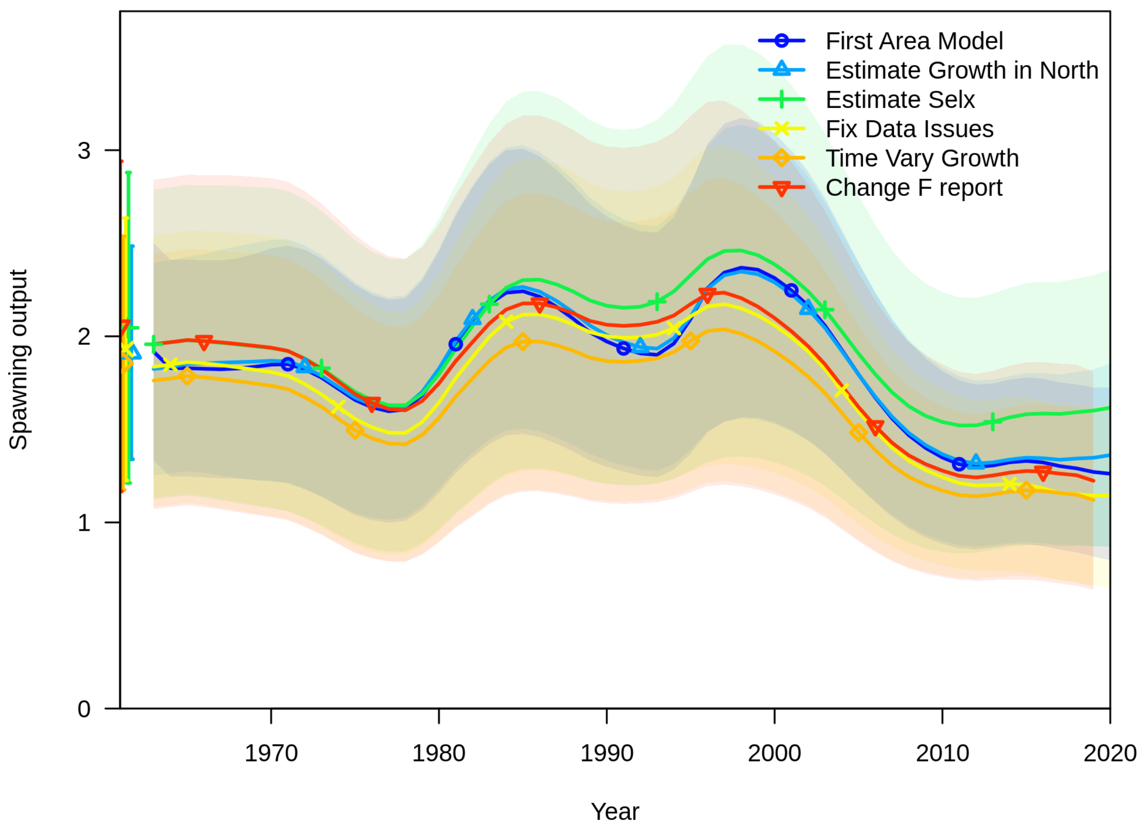



Figure 157: A comparison of the spawning output trajectories from the initial attempt to fit an area model (First Area Model) to the final stage of development for this assessment (Change F report). The changes to the model included estimating growth parameters in the north (Estimate Growth in North), estimating selectivity for the surveys in both areas (Estimate Selx), removing some commercial length composition data from 2018 that was clearly in error (Fix Data Issues), adding time varying growth parameters in the southern area (Time Vary Growth) and finally, adding some penalties to some selectivity parameters and changing the F report basis (Change F report).

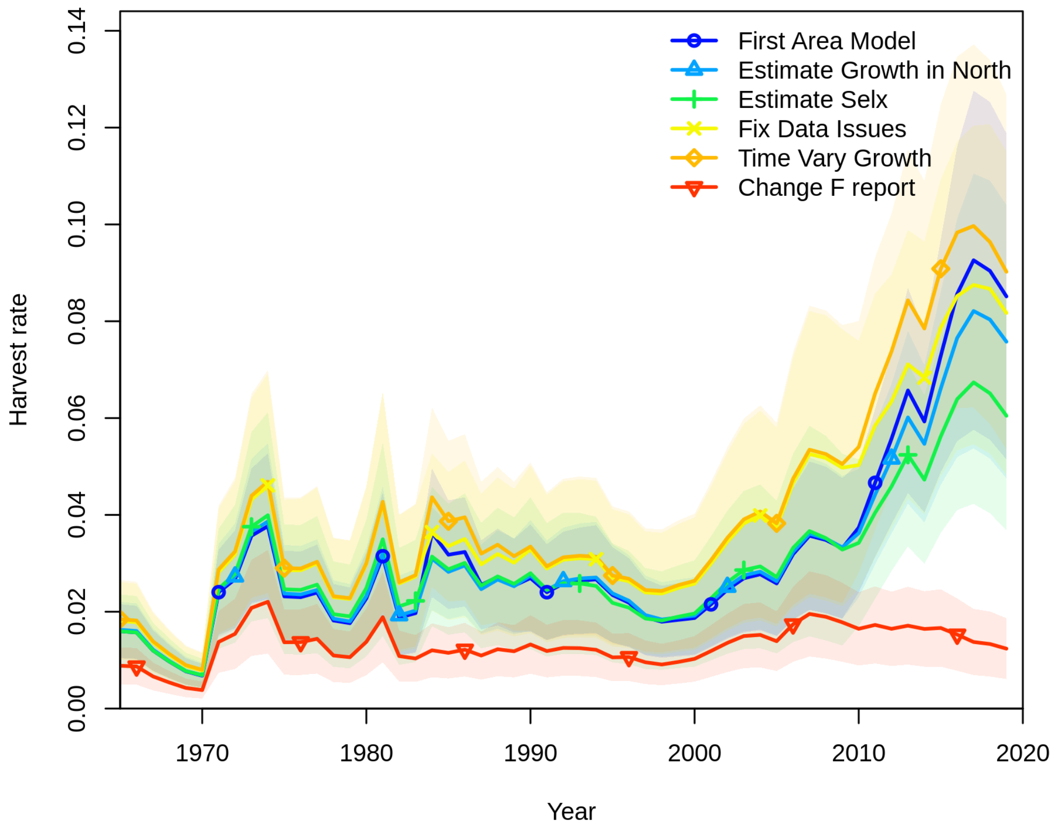



Figure 158: A comparison of the fishing mortality trajectories from the initial attempt to fit an area model (First Area Model) to the final stage of development for this assessment (Change F report). The changes to the model included estimating growth parameters in the north (Estimate Growth in North), estimating selectivity for the surveys in both areas (Estimate Selx), removing some commercial length composition data from 2018 that was clearly in error (Fix Data Issues), adding time varying growth parameters in the southern area (Time Vary Growth) and finally, adding some penalties to some selectivity parameters and changing the F report basis (Change F report).

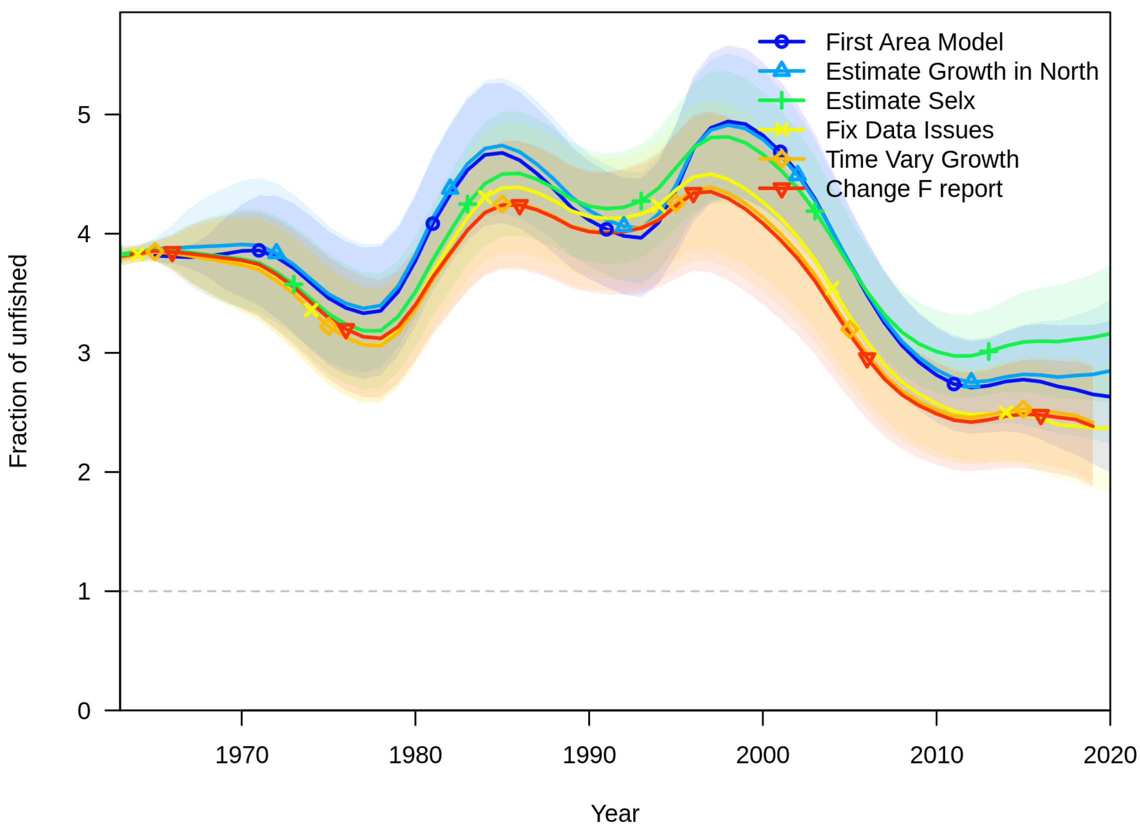



Figure 159: A comparison of the spawning output trajectories relative to initial spawning output estimates from each model (removing scale) from the initial attempt to fit an area model (First Area Model) to the final stage of development for this assessment (Change F report). The changes to the model included estimating growth parameters in the north (Estimate Growth in North), estimating selectivity for the surveys in both areas (Estimate Selx), removing some commercial length composition data from 2018 that was clearly in error (Fix Data Issues), adding time varying growth parameters in the southern area (Time Vary Growth) and finally, adding some penalties to some selectivity parameters and changing the F report basis (Change F report).

## Appendix 5 Plan B assessment

Stock abundance of Atlantic surfclam, as described in this and previous assessments is somewhat uncertain as reflected in the historical retrospective plot (Figure 117). The trend in stock abundance however, is relatively well defined over most of the time series, excepting the terminal years, and there is little doubt that the Atlantic surfclam stock is near or above its target biomass. Estimates of absolute abundance are no longer required to determine the stock status of Atlantic surfclam, but removing them from the previous assessment caused some difficulty in setting an absolute Overfishing Limit (OFL), an important task of the Mid Atlantic Fisheries Management Council's Scientific and Statistical Committee (MASSC). This document is intended to provide some additional support for the process of setting an OFL as well as providing support for the overall conclusion regarding the status of the stock and the absolute scale estimated in the assessment model.

The SSC incorporates uncertainty into the process of setting an OFL. Therefore a method exists by which the current estimates of stock abundance from the assessment could be used to set OFL. Those estimates are provided here along with some empirical measures of stock abundance intended to provide additional support for the accuracy of the estimates from the assessment.

### Assessment Results

The assessment provided estimates of the OFL based on model results (Figure 163). These included uncertainties in both the biomass estimate and the fishing mortality reference point. The OFL calculations in the assessment however, are not directly comparable to the OFL calculations below. The OFL in the assessment are based on the fishing mortality reference point calculated in the assessment. That reference point was designed to scale with the assessment model and is a function of the estimated biomass. Without running the model (and obviating the purpose of a plan B assessment) it is impossible to duplicate the reference point used. Therefore the empirical analyses below will use the reference point from (Hennen et al. 2018).

### Empirical Results

The empirical analyses presented here incorporate swept area biomass estimates. These were made using NEFSC clam survey data for all years in which instrumentation allowed a precise measure of tow distance (1997-2019). The catch, in clams per $m^2$, was determined by dividing the catch within each strata by the area swept in that strata, expanded by the area of each strata, and then summed over strata to generate an estimate for each region (eq. 6; Table 35; Figure 166). The stock assessment model used a prior distribution to help estimate catchability, which provides much of the information about the scale of abundance to the model. The prior distribution for catchability is based on depletion experiments and had high variance (Figure 164). For the purposes of this analysis, catchability was assumed to be either one, or taken from the depletion experiments. In either case, no selectivity was applied. Thus, the biomass estimate here should be considered either a lower bound on true biomass, as no fishing gear captures all animals it encounters, or an estimate of the biomass of fully selected animals. Swept area biomass is

$$\hat{B_{t,a}} = \sum_i \left[ \frac{I_{i,t,a}}{A_{i,t,a}} R_{i,a} \right] q \tag{6}$$

where $\hat{B_{t,a}}$ is the estimated biomass in region $a$ in year $t$, $I_{i,t,a}$ is the weight captured in survey tows in stratum $i$, $A_{i,t,a}$ is the total area swept by tows in stratum $i$, $R_{i,a}$ is the total area of each stratum in area $a$ and $q$ is the catchability, ($q = 1$ or 0.67). The coefficient of variation (cv) shown in Table 35 was derived from the variance of the stratified mean density observed in the survey. The variance observed in each strata was weighted by the area of the strata and then combined. All variance components were combined as

$$\widehat{\sigma_a, t} = \sqrt{\sum_i \sigma^2_{i,t,a}} \tag{7}$$

where $\sigma_{t,a}$ was the std. deviation of the mean density in year $t$ and region $a$, and $\sigma^2_{i,t,a}$ was the variance in stratum $i$, year $t$ and region $a$. Additional variation was included to account for uncertainty in the stock area (based on the difference between the survey footprint and the area where the upper 99 % quantile of animals occur - see Hennen and Jacobson *in press* described below), uncertainty in the estimated usable habitat within each area (based on the proportion of untowable ground observed in the survey in each area; (Northeast Fisheries Science Center 2017a)), uncertainty in the distance covered by a standard tow (derived from estimates of tow distance from each strata in the survey, weighted by strata area), and uncertainty in the estimate of q being used (either 0, when $q = 1$, or derived from the variance estimated in depletion experiments; see Northeast Fisheries Science Center 2017a). All cv were combined using the formula

$$cv\widehat{_{1,...,n}} = \sqrt{cv_1^2 + ... + cv_n^2} \tag{8}$$

where $cv_1, ..., cv_n$ were the $n$ cv being combined.

The estimate of exploitation rate, $\hat{E}_t$ was equal to the catch in each year divided by the minimum swept area biomass estimated in that year summed across regions.

$$\hat{E}_t = \frac{C_t}{\sum_a \hat{B_{t,a}}} \tag{9}$$

where $C_t$ is catch in year $t$. It was only possible to make this calculation directly for years in which the entire stock was surveyed, 1997-2011 (Table 36).

It is possible to approximate an Over Fishing Limit (OFL) calculation using the lower bound on swept area abundance, $\hat{B_{t,a}}$, as derived in eq. 6 as

$$O\hat{F}L = \frac{F_{MSY}}{F_{MSY} + M} \sum_a \hat{B_{t,a}} \left(1 - e^{(-(F_{MSY}+M))}\right) \tag{10}$$

where $F_{MSY} = 0.12$, and $M = 0.15$ (values taken from Northeast Fisheries Science Center 2017a; Hennen et al. 2018). Estimates of OFL (Table 39) using Eq. (10) were derived from pooling the $\hat{cv}$ (eq. 8) over area. The timing of the survey and the assessment make it necessary to use $t = 2019$ for Georges Bank and $t = 2018$ for the southern area (Southern Virginia to Southern New England) to make the calculation in eq. 10. The probability of overfishing ($F_{terminal} > F_{MSY}$) can be approximated by comparing a lognormal distribution of the exploitation rate, (with mean equal to $E_t$, and cv equal to the cv of $\hat{B_{t,a}}$; Eq. 9), to a lognormal distribtion of $F_{MSY}$ (with a mean of 0.12 and a cv of 100%). This comparison indicated a very low probability of overfishing (Figure 167), until catch was increased above the current quota (Figure 168).

The results of this analysis are consistent with the findings of the 2017 Atlantic surfclam stock assessment. The median OFL shown in Figure (127) are within the confidence bounds of the empirical OFL shown in Table (39). NEFSC intends to supply empirical estimates of stock abundance in future assessments in order to facilitate the deliberations of the MASSC.

## Reducing Uncertainty

Difficulty in estimating stock abundance historically stems largely from the lack of a precise estimate of abundance for the northern (Georges Bank) segment of the stock (see appendix for additional discussion). The northern area has been essentially unfished for the last three decades, and only recently (2011) opened to fishing. A lack of fishing results in a lack of contrast between measures of fishing and observations of stock condition from the survey. In addition, there is less survey data for the northern area. Although the survey began in 1982, the northern area has always been more difficult to survey and was often undersampled or skipped. In addition, the survey platform changed in 2012. The previous survey platform used relatively inefficient gear and resulted in a noisy survey index. At the time the stock assessment was completed, there was one survey observation using the new, more efficient, survey platform in the northern area. Increased precision is expected over time as additional survey data accumulates, and fishing continues. An update of the current Atlantic surfclam stock assessment should provide a more precise estimate of abundance due to the accumulation of data alone.

The MASSC requested a "description of the short-term and long-term research and analyses NEFSC is planning to conduct to improve our understanding of survey catchability and reduce the uncertainty in the absolute estimates [of abundance]." It is the opinion of the NEFSC that the problem of uncertainty in abundance in the Atlantic surfclam stock assessment does not primarily result from a lack of understanding of survey catchability. In fact survey catchability is probably better understood (empirically) in the NEFSC clam survey that in most of the other fishery surveys in the world. NEFSC has conducted more than 20 depletion experiments in order to estimate survey catchability and uses the results of these studies to inform prior distributions around survey catchability in the assessment model (Northeast Fisheries Science Center 2017a). Estimating absolute abundance imprecisely is common in fisheries with low fishing intensity and relatively little contrast in the time series of stock abundance indices. These endemic challenges are not typically correctable through research or analysis, which cannot generate additional fishing pressure, or induce contrast in the survey indices. NEFSC has, however, undertaken to improve the precision of the estimates of abundance from the survey. A nearly 2 year project to redesign the NEFSC clam survey with the goal of providing increased precision was recently completed and published as a Center Reference Document Jacobson and Hennen (2019). A survey of the southern area using the survey protocols developed during this process took place in August of 2018 and on Georges Bank in 2019. The proposed changes to the survey are expected to increase the precision of survey abundance estimates.

Table 34: Whole stock age 6+ biomass (mt) for Atlantic surfclam for the 2019 assessment.

| Year | Biomass | CV | upper | lower |
|---|---|---|---|---|
| 1963 | 1609692.00 | 0.23 | 2337288.35 | 882095.65 |
| 1964 | 1620690.00 | 0.23 | 2349425.93 | 891954.07 |
| 1965 | 1630818.00 | 0.23 | 2361689.69 | 899946.31 |
| 1966 | 1625507.00 | 0.23 | 2359061.90 | 891952.10 |
| 1967 | 1620546.00 | 0.23 | 2360428.95 | 880663.05 |
| 1968 | 1619236.00 | 0.24 | 2366157.09 | 872314.91 |
| 1969 | 1629470.00 | 0.24 | 2388235.10 | 870704.90 |
| 1970 | 1623742.00 | 0.24 | 2386141.53 | 861342.47 |
| 1971 | 1609955.00 | 0.24 | 2371537.10 | 848372.90 |
| 1972 | 1590292.00 | 0.25 | 2354037.10 | 826546.90 |
| 1973 | 1561520.00 | 0.25 | 2323095.60 | 799944.40 |
| 1974 | 1520219.00 | 0.25 | 2275413.76 | 765024.24 |
| 1975 | 1463382.00 | 0.26 | 2202810.70 | 723953.30 |
| 1976 | 1411702.00 | 0.26 | 2129743.36 | 693660.64 |
| 1977 | 1357446.00 | 0.26 | 2049612.78 | 665279.22 |
| 1978 | 1310278.00 | 0.26 | 1975906.26 | 644649.74 |
| 1979 | 1281969.00 | 0.25 | 1922143.92 | 641794.08 |
| 1980 | 1255462.00 | 0.25 | 1868983.77 | 641940.23 |
| 1981 | 1260743.00 | 0.24 | 1865256.32 | 656229.68 |
| 1982 | 1319213.00 | 0.24 | 1945776.28 | 692649.72 |
| 1983 | 1521885.00 | 0.24 | 2236213.25 | 807556.75 |
| 1984 | 1633822.00 | 0.24 | 2394505.07 | 873138.93 |
| 1985 | 1713074.00 | 0.24 | 2508413.75 | 917734.25 |
| 1986 | 1810061.00 | 0.24 | 2649780.80 | 970341.20 |
| 1987 | 1844905.00 | 0.24 | 2701263.55 | 988546.45 |
| 1988 | 1802470.00 | 0.24 | 2639215.25 | 965724.75 |
| 1989 | 1770101.00 | 0.24 | 2592834.38 | 947367.62 |
| 1990 | 1737618.00 | 0.24 | 2545060.70 | 930175.30 |
| 1991 | 1655795.00 | 0.24 | 2426048.67 | 885541.33 |
| 1992 | 1620429.00 | 0.24 | 2374712.32 | 866145.68 |
| 1993 | 1606178.00 | 0.24 | 2354746.99 | 857609.01 |
| 1994 | 1632560.00 | 0.24 | 2393145.43 | 871974.57 |
| 1995 | 1665462.00 | 0.24 | 2440285.33 | 890638.67 |
| 1996 | 1632813.00 | 0.24 | 2389602.44 | 876023.56 |
| 1997 | 1688270.00 | 0.24 | 2467148.99 | 909391.01 |
| 1998 | 1829077.00 | 0.23 | 2667910.03 | 990243.97 |
| 1999 | 1861160.00 | 0.23 | 2708224.48 | 1014095.52 |
| 2000 | 1803739.00 | 0.23 | 2618468.53 | 989009.47 |
| 2001 | 1754185.00 | 0.23 | 2540786.48 | 967583.52 |
| 2002 | 1684534.00 | 0.23 | 2435720.63 | 933347.37 |
| 2003 | 1592029.00 | 0.23 | 2299939.84 | 884118.16 |
| 2004 | 1524037.00 | 0.23 | 2201799.95 | 846274.05 |
| 2005 | 1460972.00 | 0.23 | 2111263.62 | 810680.38 |
| 2006 | 1351985.00 | 0.23 | 1953640.09 | 750329.91 |

| | | | | |
|---|---|---|---|---|
| 2007 | 1243983.00 | 0.23 | 1798507.31 | 689458.69 |
| 2008 | 1144726.00 | 0.23 | 1655890.98 | 633561.02 |
| 2009 | 1058732.00 | 0.23 | 1531716.03 | 585747.97 |
| 2010 | 995932.00 | 0.23 | 1440965.01 | 550898.99 |
| 2011 | 969189.00 | 0.23 | 1402198.16 | 536179.84 |
| 2012 | 959025.00 | 0.23 | 1387959.99 | 530090.01 |
| 2013 | 925219.00 | 0.23 | 1340438.00 | 510000.00 |
| 2014 | 905614.00 | 0.23 | 1315397.45 | 495830.55 |
| 2015 | 909058.00 | 0.23 | 1324833.10 | 493282.90 |
| 2016 | 931784.00 | 0.24 | 1362711.09 | 500856.91 |
| 2017 | 960787.00 | 0.24 | 1410282.80 | 511291.20 |
| 2018 | 957922.00 | 0.24 | 1411962.68 | 503881.32 |
| 2019 | 932712.00 | 0.24 | 1379382.85 | 486041.15 |

Table 35: Minimum swept area biomass estimates of Atlantic surfclam by stock assessment region. Estimates are based on expansion of observed NEFSC survey density to area of stock in each region. Catchability was assumed to be 1 and all sizes were assumed to be fully selected. Therefore, the estimates shown here should be considered a lower bound on biomass.

| Region | Year | Biomass (1000 mt) | cv |
|---|---|---|---|
| GBK | 1997 | 165.42 | 0.31 |
| GBK | 1999 | 156.49 | 0.50 |
| GBK | 2002 | 79.12 | 0.66 |
| GBK | 2008 | 189.45 | 0.32 |
| GBK | 2011 | 147.36 | 0.32 |
| GBK | 2013 | 101.89 | 0.52 |
| GBK | 2016 | 125.97 | 0.34 |
| GBK | 2019 | 40.57 | 0.26 |
| SVAtoSNE | 1997 | 444.40 | 0.20 |
| SVAtoSNE | 1999 | 325.46 | 0.25 |
| SVAtoSNE | 2002 | 338.82 | 0.21 |
| SVAtoSNE | 2005 | 155.64 | 0.22 |
| SVAtoSNE | 2008 | 189.50 | 0.22 |
| SVAtoSNE | 2011 | 179.92 | 0.23 |
| SVAtoSNE | 2012 | 561.92 | 0.25 |
| SVAtoSNE | 2015 | 513.46 | 0.23 |
| SVAtoSNE | 2018 | 491.15 | 0.21 |

Table 36: Minimum swept area biomass estimates, catch (landings*1.12 to account for incidental mortality) and approximate exploitation rate of Atlantic surfclam in selected years.

| Year | Min. Biomass (1000 mt) | Catch (1000 mt) | $\frac{Catch}{Biomass}$ |
|---|---|---|---|
| 1997 | 609.82 | 18.61 | 0.03 |

| | | | |
|---|---|---|---|
| 1999 | 481.95 | 19.58 | 0.05 |
| 2002 | 417.94 | 24.01 | 0.06 |
| 2008 | 378.94 | 22.51 | 0.07 |
| 2011 | 327.28 | 18.84 | 0.06 |

Table 37: Efficiency corrected swept area biomass estimates of Atlantic surfclam by stock assessment region. Estimates are based on expansion of observed NEFSC survey density to area of stock in each region. Catchability was derived from depletion experiments all sizes were assumed to be fully selected.

| Region | Year | Biomass (1000 mt) | cv |
|---|---|---|---|
| GBK | 1997 | 706.92 | 1.36 |
| GBK | 1999 | 668.77 | 1.41 |
| GBK | 2002 | 338.11 | 1.47 |
| GBK | 2008 | 809.60 | 1.36 |
| GBK | 2011 | 629.74 | 1.36 |
| GBK | 2013 | 151.13 | 0.57 |
| GBK | 2016 | 186.85 | 0.41 |
| GBK | 2019 | 60.18 | 0.35 |
| SVAtoSNE | 1997 | 1899.14 | 1.34 |
| SVAtoSNE | 1999 | 1390.86 | 1.34 |
| SVAtoSNE | 2002 | 1447.94 | 1.34 |
| SVAtoSNE | 2005 | 665.13 | 1.34 |
| SVAtoSNE | 2008 | 809.82 | 1.34 |
| SVAtoSNE | 2011 | 768.91 | 1.34 |
| SVAtoSNE | 2012 | 833.50 | 0.33 |
| SVAtoSNE | 2015 | 761.62 | 0.32 |
| SVAtoSNE | 2018 | 728.53 | 0.31 |

Table 38: Efficiency corrected swept area biomass estimates, catch (landings*1.12 to account for incidental mortality) and approximate exploitation rate of Atlantic surfclam in selected years.

| Year | Biomass (1000 mt) | Catch (1000 mt) | $\frac{Catch}{Biomass}$ |
|---|---|---|---|
| 1997 | 2606.06 | 18.61 | 0.01 |
| 1999 | 2059.62 | 19.58 | 0.01 |
| 2002 | 1786.05 | 24.01 | 0.02 |
| 2008 | 1619.42 | 22.51 | 0.02 |
| 2011 | 1398.64 | 18.84 | 0.02 |

Table 39: Estimates of the overfishing limit (OFL) based on swept area biomass estimates, using $F_{MSY} = 0.12$ and $M = 0.15$. The lower bound estimates are not corrected for efficiency $q = 1$, while the efficiency corrected estimates use $q = 0.67$. The confidence intervals (Lower and Upper) are assymmetric approximations based on the estimated coefficienct of variation (cv).

| | OFL (1000 mt) | cv | Lower (1000 mt) | Upper (1000 mt) |
|---|---|---|---|---|
| Lower bound | 67 | 0.29 | 38 | 117 |
| Efficiency corrected | 100 | 0.37 | 50 | 201 |

Table 40: The difference in area ($nm^2$) between the survey strata used from 1982-2016 and the strata used after 2017 by area.

| | Old | New | Change |
|---|---|---|---|
| North | 5772 | 5028 | 0.87 |
| South | 16983 | 10750 | 0.63 |

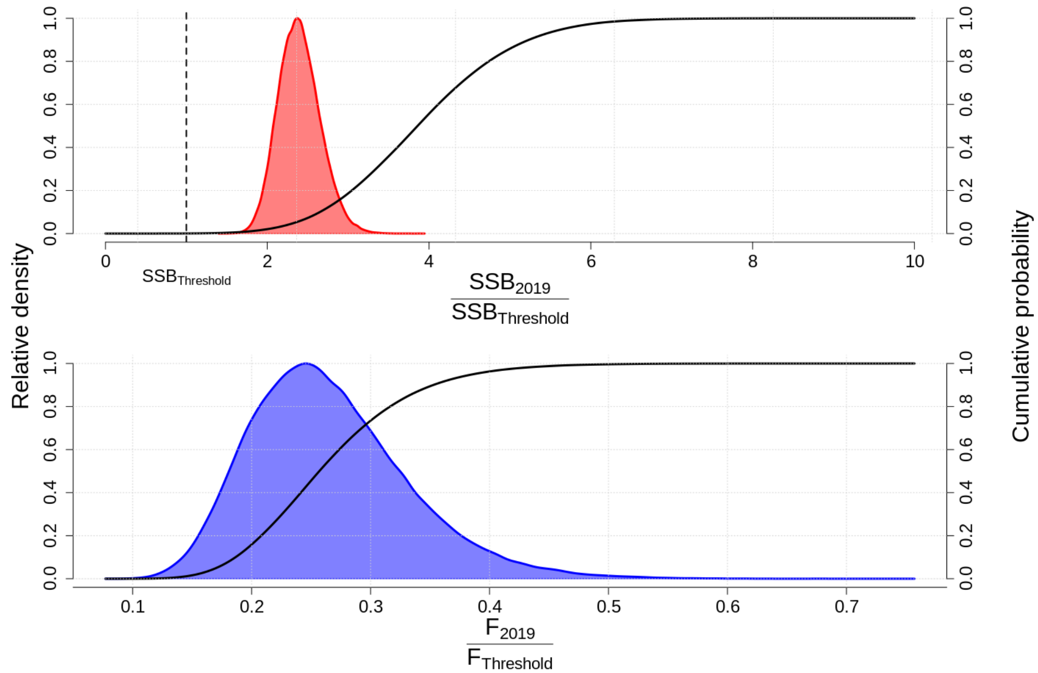



Figure 160: Probability distributions of $\frac{B_{2019}}{B_{Threshold}}$ and $\frac{F_{2019}}{F_{Threshold}}$, using the recommended reference points. The probability of overfished status during 2019 is equal to the area of the red, upper curve that is less than $B_{Threshold}$. The probability of overfishing status during 2019 is equal to the area of the blue, lower curve that is greater than $F_{Threshold}$. The probability of overfished and overfishing status can be approximated by the elevation (y axis scale) at which the solid line representing the cumulative probability distribution crosses the dashed vertical line representing the reference point in each plot. The probability distributions presented in this figure account for the positive correlation between the reference points ($B_{Threshold} = \frac{B_0}{4}$ and $F_{OFL} = F_{Threshold} = F^* \frac{F_{MSY}}{F^*_{Max}}$) and the fishing mortality and biomass estimates in 2019, as well as the uncertainty in the estimation of both the point estimates and their respective reference points.

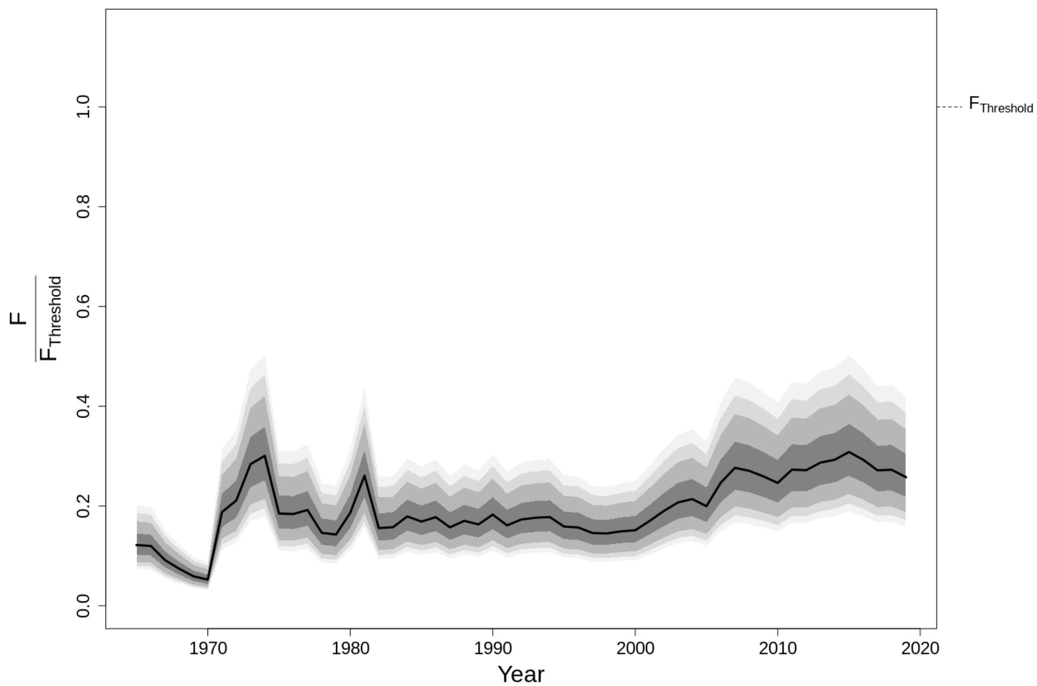



Figure 161: The time series of the ratio of fishing mortality estimates to the recommended $F$ threshold, with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between $F$ and $F_{Threshold}$. Over fishing would occur if the ratio exceed 1.0.

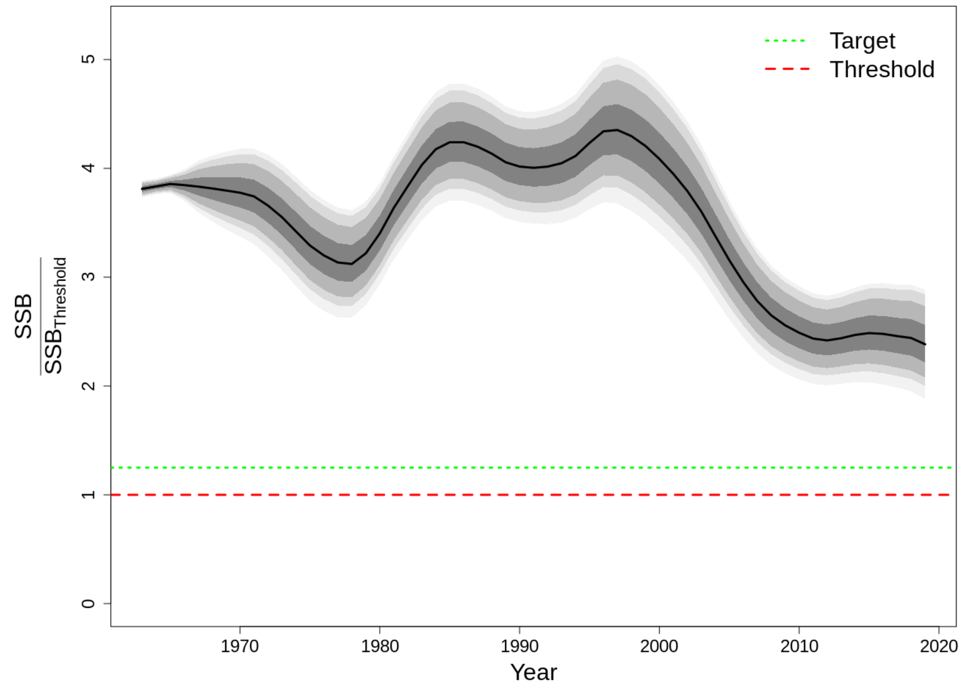



Figure 162: The time series of the ratio of biomass estimates to the unfished biomass ($B_0$), with the 50, 80, 90, and 95 % lognormal confidence intervals in shades of gray. The confidence intervals account for the correlation between $B$ and $B_0$. Overfished status would occur if the ratio went below 0.25.

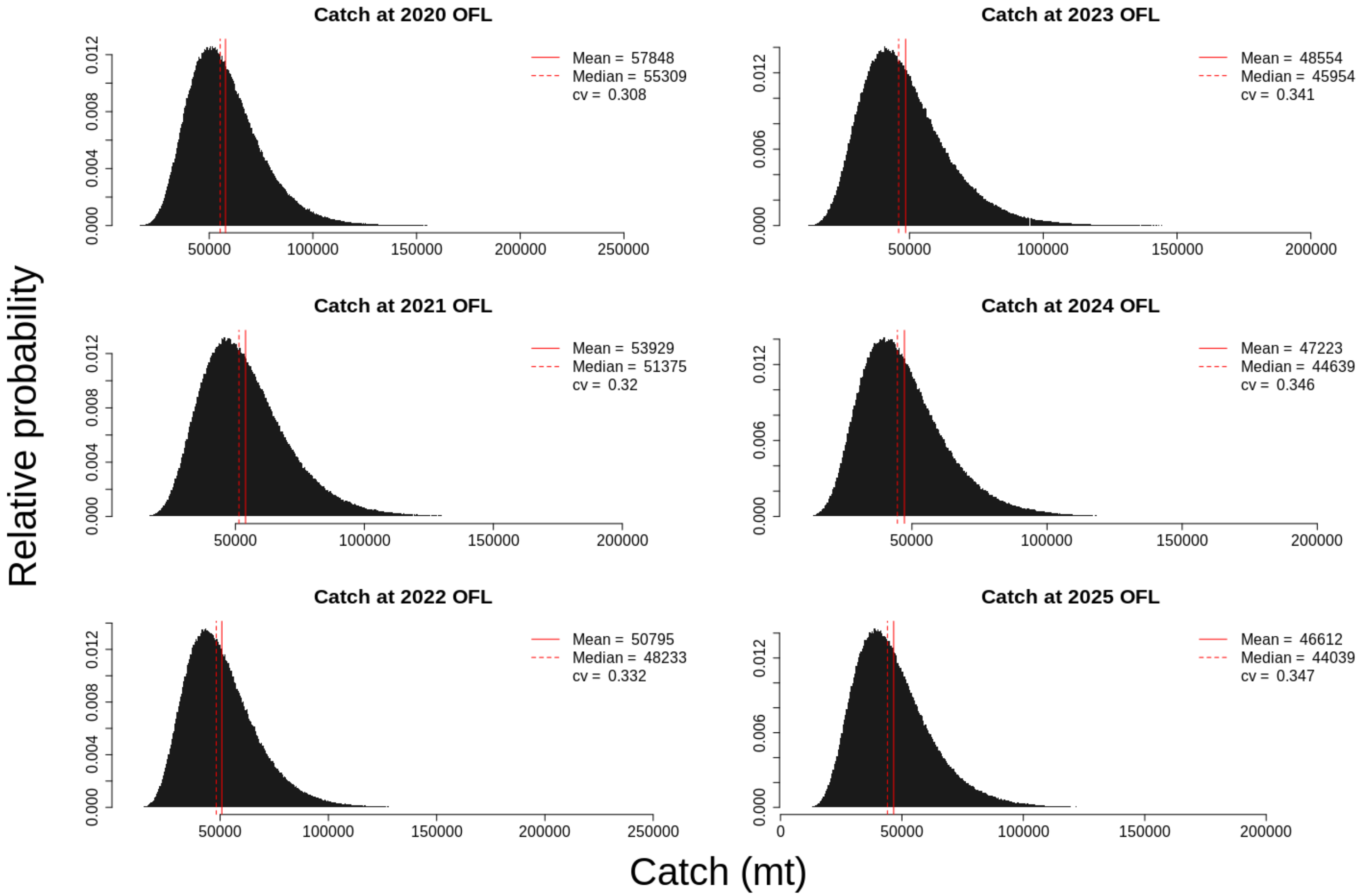



Figure 163: Distribution of catch (landings + incidental mortality) at the Over Fishing Limit (OFL) from 2020-2026 for Atlantic surfclam.

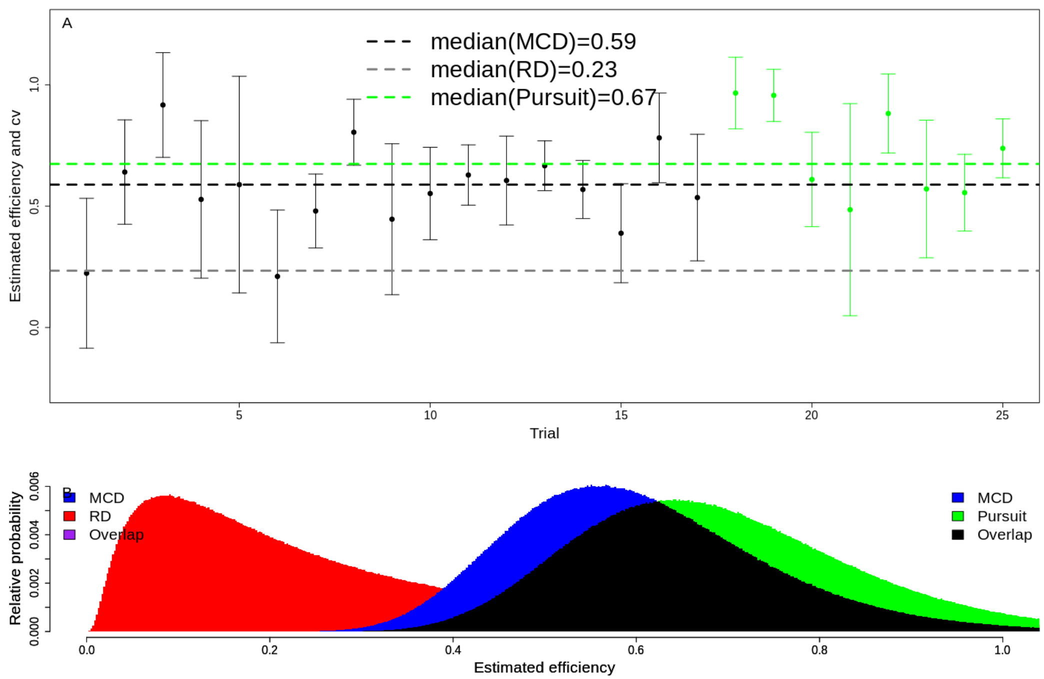



Figure 164: Panel A) Individual modified commercial dredge (MCD) capture efficiency estimates with coefficients of variation compared to median values for the MCD and the survey dredge used from the research vessel (RD) as well as the specific dredge used on the current survey (Pursuit). Panel B) A comparison of median values values incoprorating the pooled cv for each dredge where each is shown as a truncated lognormal distribution. The MCD and Pursuit dredge had higher and more precisely estimated capture efficiency than the RD.

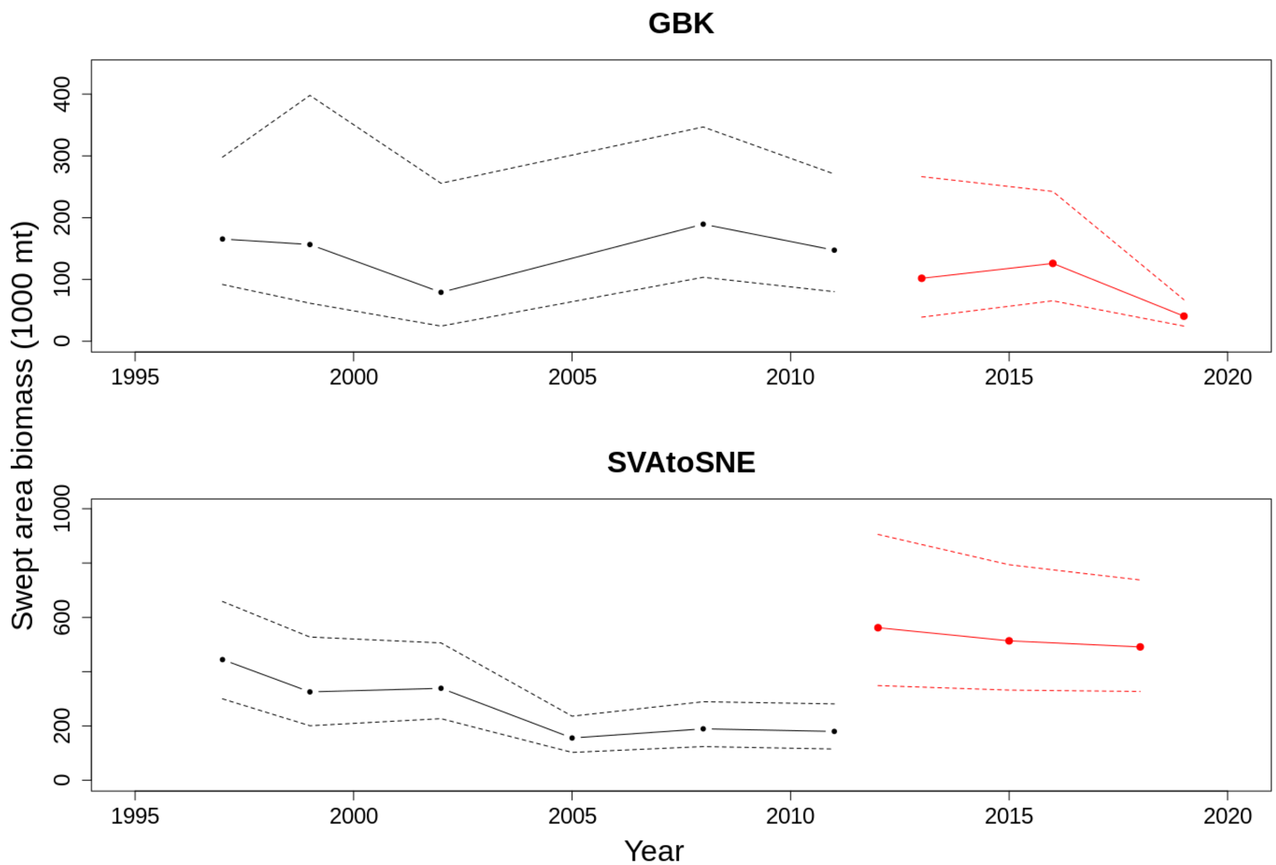



Figure 165: Trends in minimum swept area biomass estimates for Atlantic surfclam in thousands of metric tons. The NEFSC survey switched to a commercial platform in 2012, creating a separate index which is shown in red. The confidence intervals are asymmetric $95\%$ approximations based on the coefficient of variation shown in Table 35.

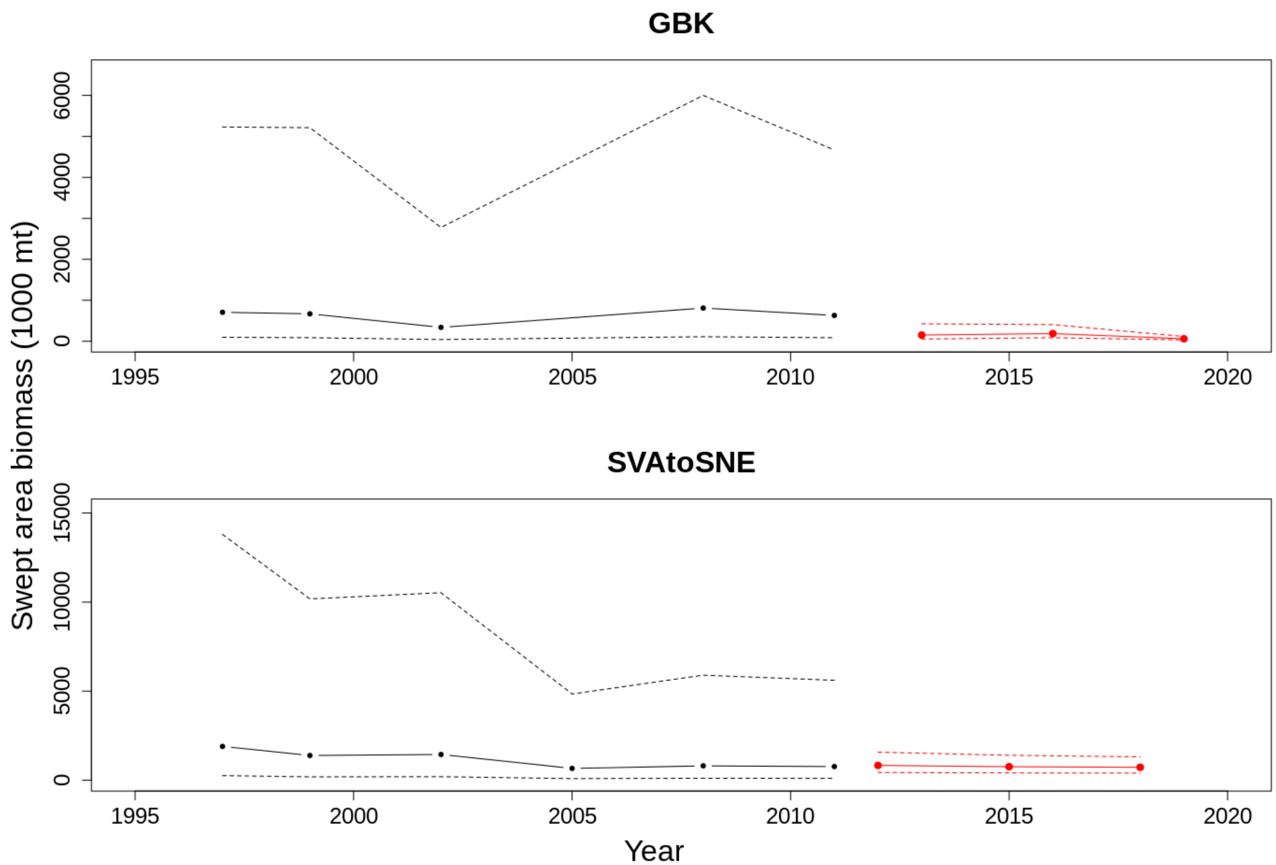



Figure 166: Trends in efficiency corrected swept area biomass estimates for Atlantic surfclam in thousands of metric tons. The NEFSC survey switched to a commercial platform in 2012, creating a separate index which is shown in red. The confidence intervals are asymmetric $95\%$ approximations based on the coefficient of variation shown in Table 35.

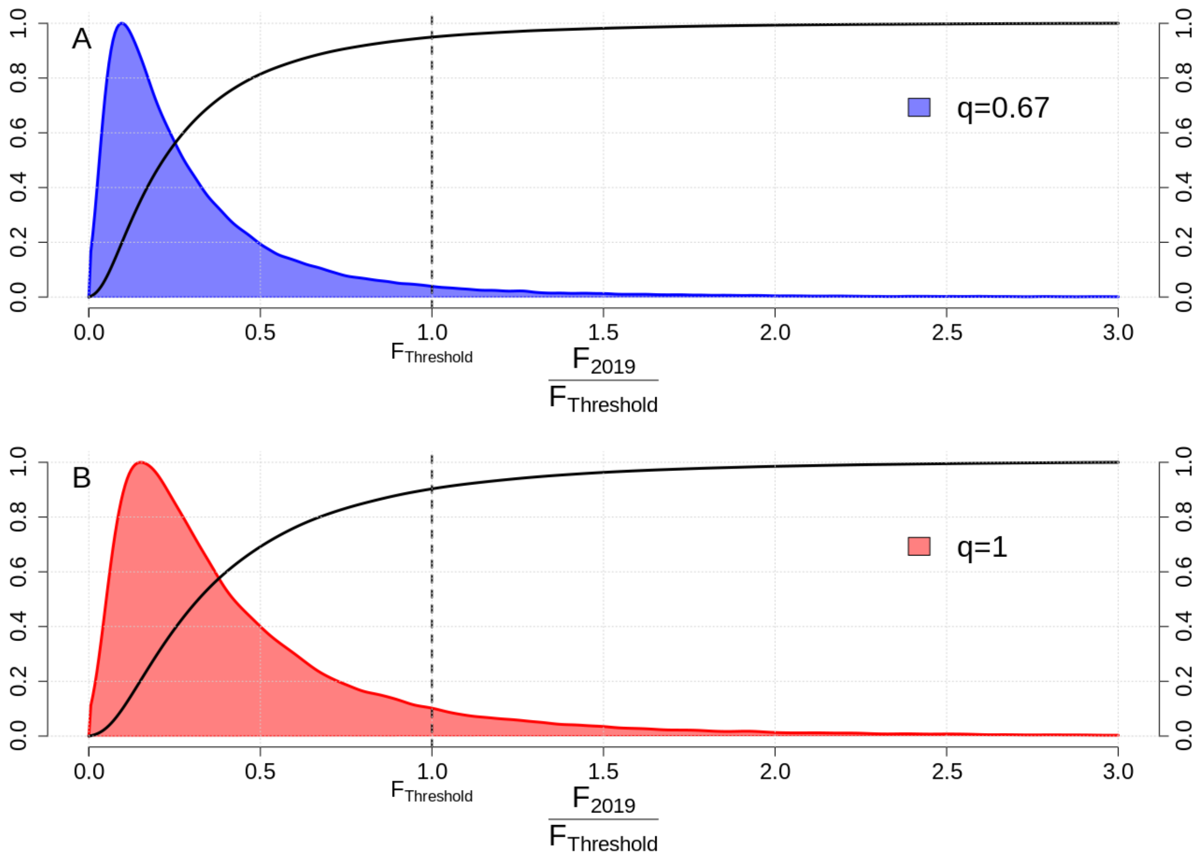



Figure 167: Probability distribution of $\frac{F_{2017}}{F_{Threshold}}$, using $F_{Threshold} = 0.12$. The probability of overfishing status during 2017 is equal to the area of the blue curve that is greater than $F_{Threshold}$. The probability of overfishing status can be approximated by the elevation (y axis scale) at which the solid line representing the cumulative probability distribution crosses the dashed vertical line representing the reference point. Panel (A) shows the results when swept area biomass calculations assume catchability=0.67 and in panel (B) catchability =1.0. The probabilities presented in this figure account for the uncertainty in the estimation of both the point estimate and reference point.

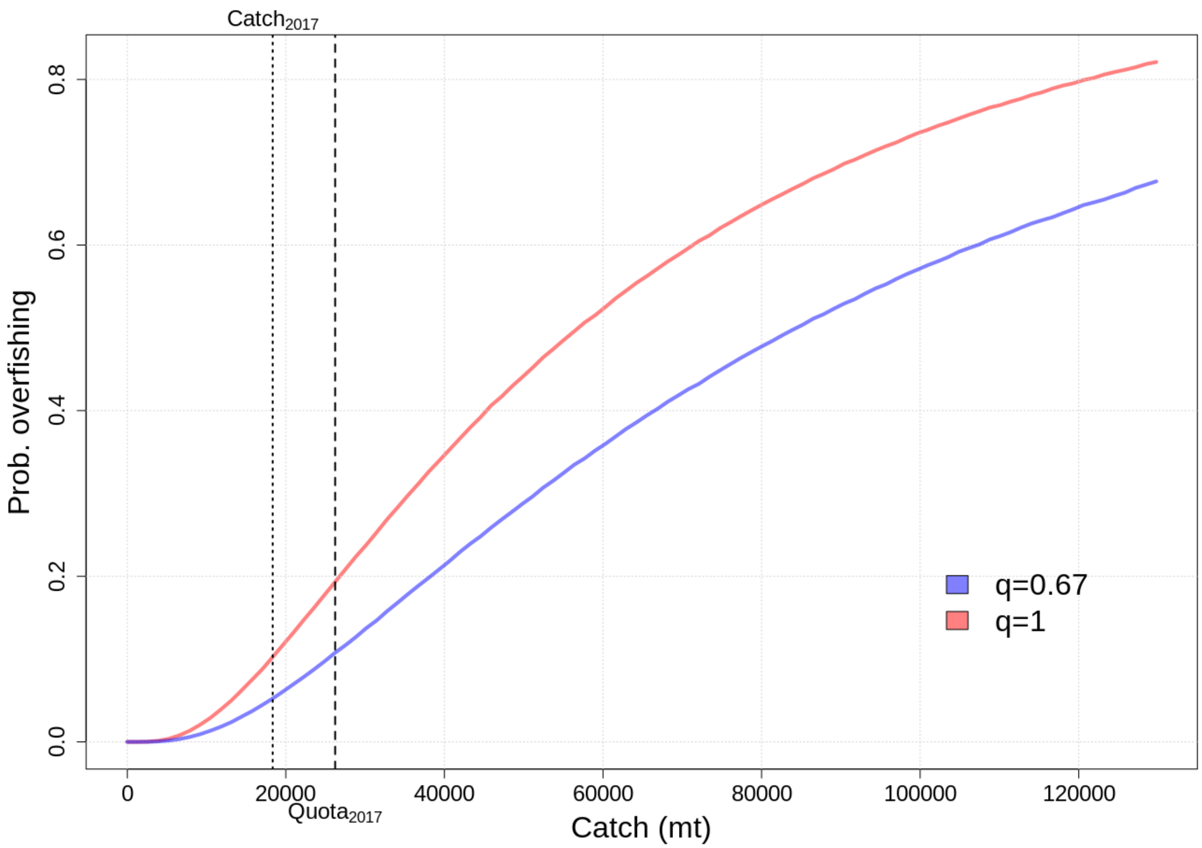



Figure 168: The probability of overfishing given different levels of catch. The blue line the results from swept area biomass where catchability=0.67 and for the red line, catchability =1.0. The probabilities presented in this figure account for the uncertainty in the estimation of both the point estimate and reference point.

## Appendix 6 Appendix: A closer look at Georges Bank

The estimates of minimum abundance on Georges Bank (GBK or northern area) are lower after 2012 than before. Given that the industry platform is much more efficient than the gear used before 2012 (Figure 164), the estimates of abundance should be substantially higher after 2012 if the population has been approximately stable (this is evident in the southern area; Figure 166). The implied reduction in biomass were thought not to be due to fishing removals which were thought to be low (Northeast Fisheries Science Center 2017a). Therefore the GBK survey was examined closely to determine potential causes of this unexpected behavior. The result is that the perception of the abundance on GBK has changed and it now appears that there are fewer Atlantic surfclam there than previously believed.

The swept area estimates for GBK have had high cv relative to swept area estimates from the southern area (Table 35). In general, GBK is more difficult to survey than the southern area due to various factors including the presence of rocks, rough bottom, strong currents and patchiness of the resource. Certain strata were frequently missed due to time constraints (GBK was typically surveyed after the southern area) or broken equipment. Individual strata on Georges Bank appeared unstable during the period of no fishing (prior to 2011; Figure 169). This indicates poor survey performance as changes in swept area biomass cannot be due to fishing activity. Atlantic surfclam density on GBK has relatively high spatial variance. Patchy resources require relatively high sample sizes to reduce uncertainty. The NEFSC clam survey has measured high uncertainty in strata on GBK in most years (Figure 170). The high uncertainty probably reflects inadequate sampling efforts, as the number of tows is inversely proportional to the variance of the mean in a stratum (Cochran 1977). In some years, such as 2002 and 2011, the strata that made the largest contribution to swept area biomass had very few tows (Figure 171). Increasing the number of tows per stratum was a goal of the NEFSC clam survey starting in 2011 (see Figure 169 for a trend over all strata). The number of tows per stratum should increase further starting in 2019 due to the reduction in the number of strata in each area resulting from the redesign of the survey. For example, there are 6 strata in the north and the south currently, while previously there were 14 and 41 respectively.

Restratifying the NEFSC clam survey has improved the sampling rate considerably. This has resulted in more logical survey results. Under the previous stratification, for example, Strata 72 contributed 51% of the total biomass in 2008, but only 15% in 2011. That decline in only 3 years is unlikely given the lack of substantial removals by the fishery over that period. During the same period, strata 69 went from 0 to 23% of the total biomass. Also unlikely given that the population should be near equilibrium biomass after almost 30 years without fishing and should not be able to sustain such a large increase in biomass. Stratum 69 was sampled only once in both years, while stratum 72 was sampled 4 times in 2008 and 5 times in 2011. Both were probably undersampled in both years. In 2011 stratum 69 had the highest observed biomass and was sampled once. After post-stratification, the strata with the fewest tows are generally the ones with the lowest biomass. Additionally, the strata with the highest biomass in a particular year tend to remain at high biomass in the next survey.

It now appears that the perception of high biomass on GBK early in the time series is unlikely. The last three observations in the survey, 2013, 2016 and 2019 are the lowest in the time series when corrected for vessel efficiency. They are also very likely to be of the highest quality. The tows per stratum are the highest and the cv around the stratified means for each strata are the lowest in the time series. 2019 was the first year that the survey has been run under the new stratification system, which was motivated largely by a desire to sample GBK better. The efficiency corrected swept area biomass has gone from 151,000 mt in 2013 to 60,000 mt in 2019. During that period the fishery removed about 105,000 mt (including incidental mortality). Assuming that growth, recruitment and natural mortality roughly balance out, these values argue for a reasonably accurate survey over this period.

In contrast, the survey prior to 2012 appears noisy. The efficiency corrected swept area biomass in 1999 was 669,000 mt, in 2002 it was 338,000 mt and in 2008 it was 810,000 mt. These swings in abundance occurred when there was no fishing at all on GBK and the population should have been near it's equilibrium biomass and been relatively stable. It is possible that the survey noise is real and the population has experienced large swings that have left no evidence visible to the survey. There was no evidence of mass mortality, such as a disproportionate abundance of articulated but empty shells. Likewise there was no evidence of an usually large recruitment event, such as a strong signal in the size composition data for the area (see (Northeast Fisheries Science Center 2017a)). Given the lack of evidence for a large scale shift in the population, the noise in the survey index is probably just noise. That is, that the survey on GBK probably performed poorly prior to 2012.

Given the relative quality of the survey prior to 2012 and the survey afterward, the perception of the abundance on GBK has changed and is currently believed to be low. It may never have been very high in fact and the lack of a quality survey over the early part of the time series makes determination of it's unfished abundance difficult.

Table 41: Mean (Mean) kg per tow with relative standard error (se/mean) (Rse), by strata and year on Georges Bank. Only years where tow distance was known are included.

| | 1997 | | 1999 | | 2002 | | 2008 | | 2011 | | 2013 | | 2016 | | 2019 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Rse | Mean | Rse | Mean | Rse | Mean | Rse | Mean | Rse | Mean | Rse | Mean | Rse | Mean | Rse |
| 7S | 0.34 | 1.00 | 0.34 | 0.80 | | 0.00 | 0.02 | 0.20 | 1.05 | 0.20 | 19.91 | 0.85 | 0.01 | 0.78 | 0.03 | 0.96 |
| 8S | 24.29 | 1.00 | 6.16 | 1.00 | 0.80 | | 0.68 | 1.00 | 33.89 | 1.00 | 1.38 | 0.79 | 43.66 | 0.74 | 12.79 | 0.54 |
| 9S | 1.35 | 0.54 | 5.05 | 0.86 | 6.69 | 0.99 | 12.83 | 0.94 | 17.94 | 0.37 | 11.55 | 0.79 | 4.66 | 0.49 | 8.69 | 0.41 |
| 10S | 0.03 | 0.63 | 0.13 | 1.00 | 0.44 | 0.73 | 0.14 | 0.94 | 0.14 | 0.56 | 0.13 | 0.59 | 0.64 | 0.47 | 2.19 | 0.44 |
| 11S | 128.60 | 0.74 | 143.03 | 0.54 | 59.89 | 1.00 | 178.33 | 0.46 | 90.88 | 0.36 | 46.11 | 0.57 | 66.29 | 0.64 | 18.64 | 0.33 |
| 12S | 33.39 | 0.30 | 23.14 | 0.56 | 15.71 | 0.83 | 23.33 | 0.28 | 23.58 | 0.43 | 36.71 | 0.98 | 27.91 | 0.41 | 3.78 | 0.31 |

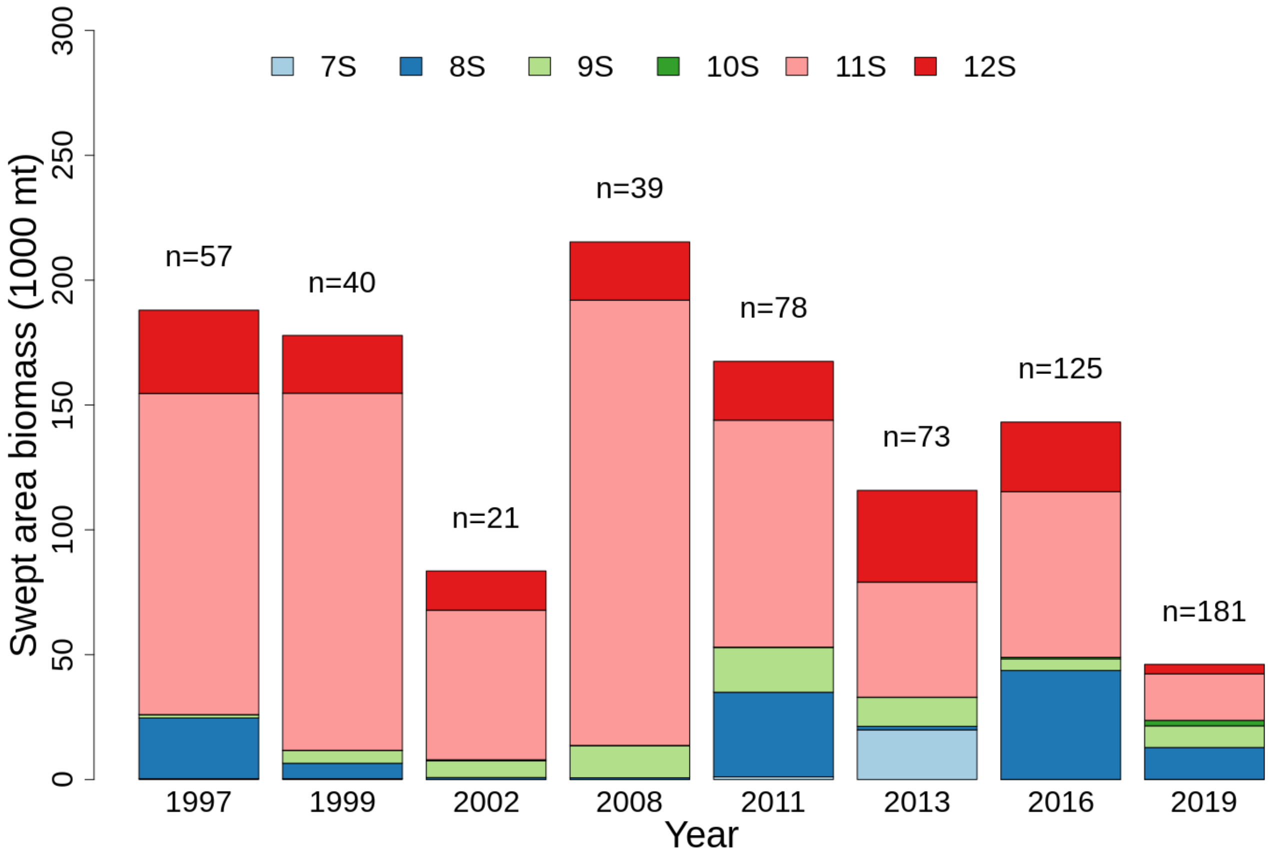



Figure 169: GBK swept area biomass by strata.

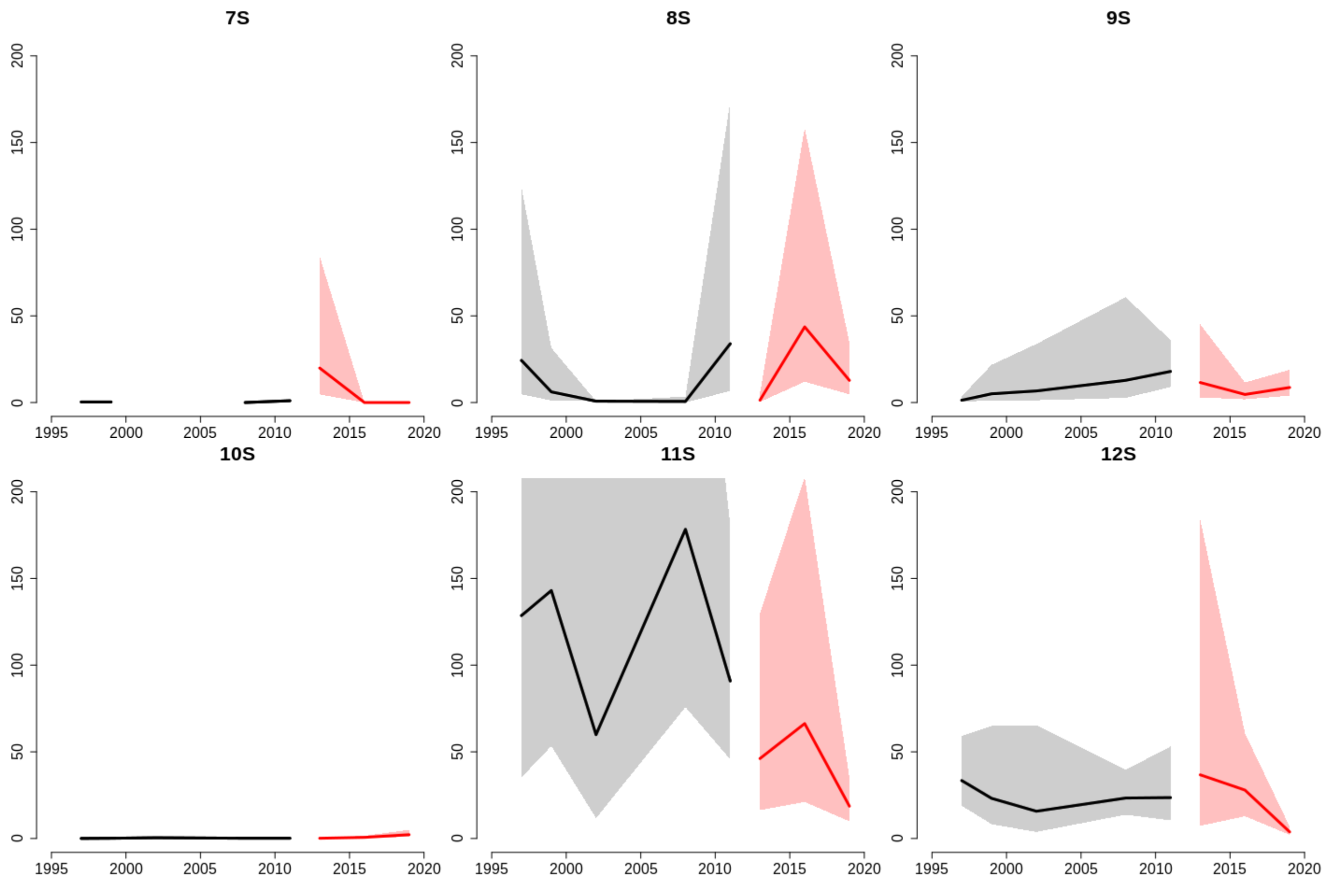



Figure 170: GBK swept area biomass and approximate $95\%$ asymmetric confidence region, by strata.

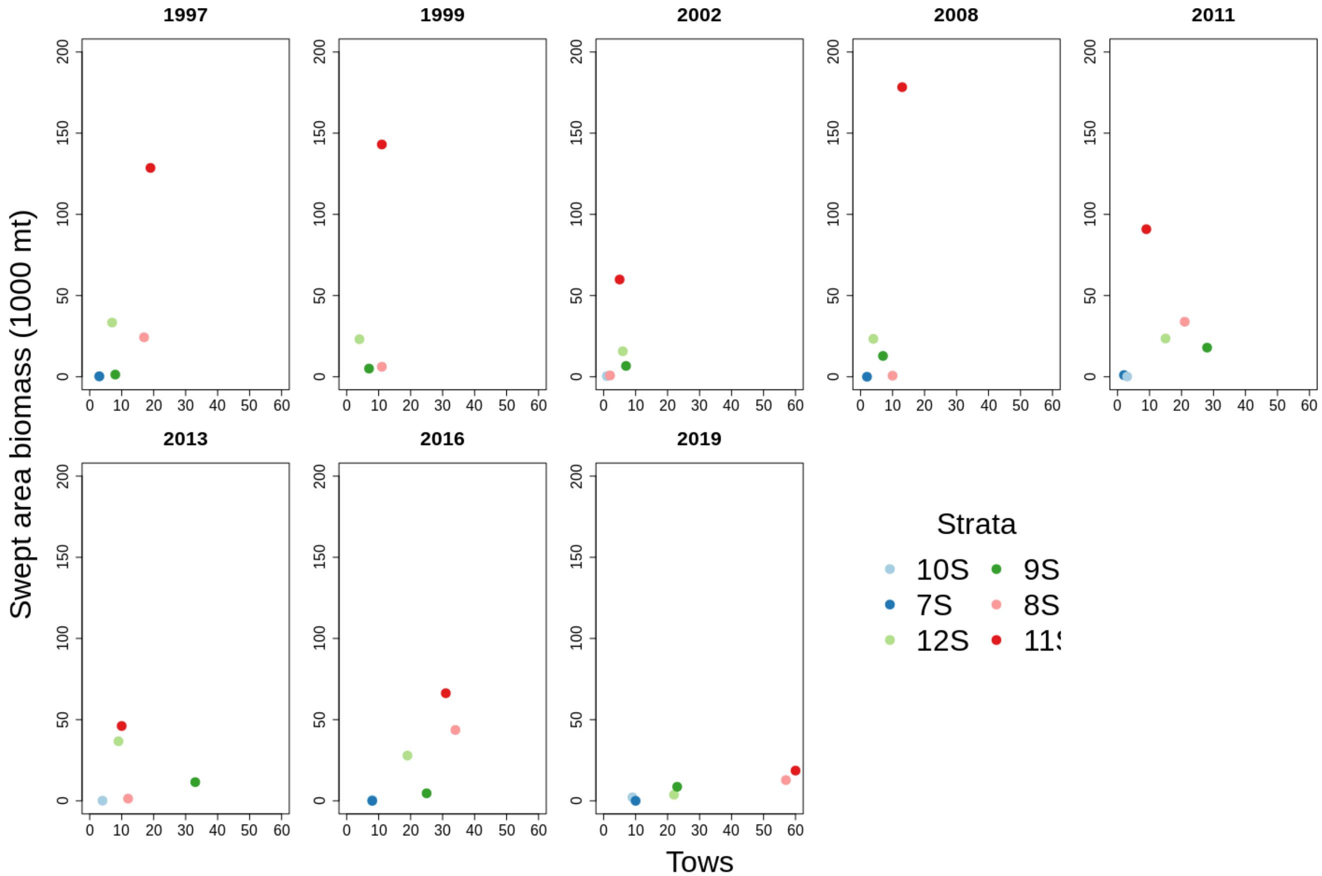



Figure 171: GBK swept area biomass and the number of tows taken in the survey in each strata, by year.

# Appendix 7 Survey performance 2016

## Introduction

The 2016 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2016 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch, roll, and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

## Survey performance

Sensors deployed during the 2016 survey suggest speed over ground was slightly less than 2012, but consistent with the years since (Figure 180). Pump pressure was close to the 2012 median (Figure 180) and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

## Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by an inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within $\Delta_{crit}$ (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow $t$), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing

effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of $\Delta_{crit}$ was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of $\Delta_{crit}$ were used. In general higher values of $\Delta_{crit}$ result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 181). We selected a $\Delta_{crit}$ of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*).

Time fishing during the 2016 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 182).

### Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2016 survey (Figure 182).

### Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2016 survey (Figure 183). Temperature was correlated with depth (Figure 183).

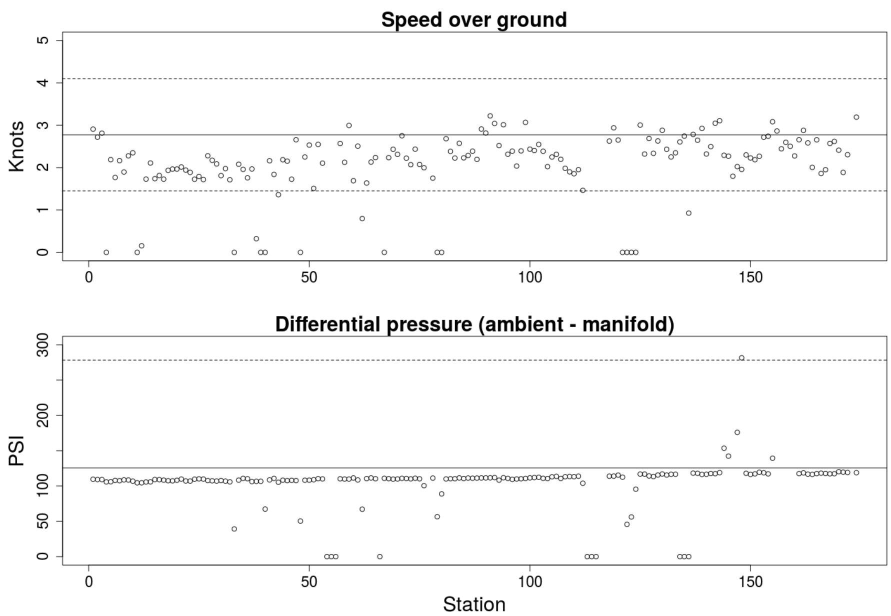



Figure 172: Speed over ground and differential pressure for each tow in the 2016 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

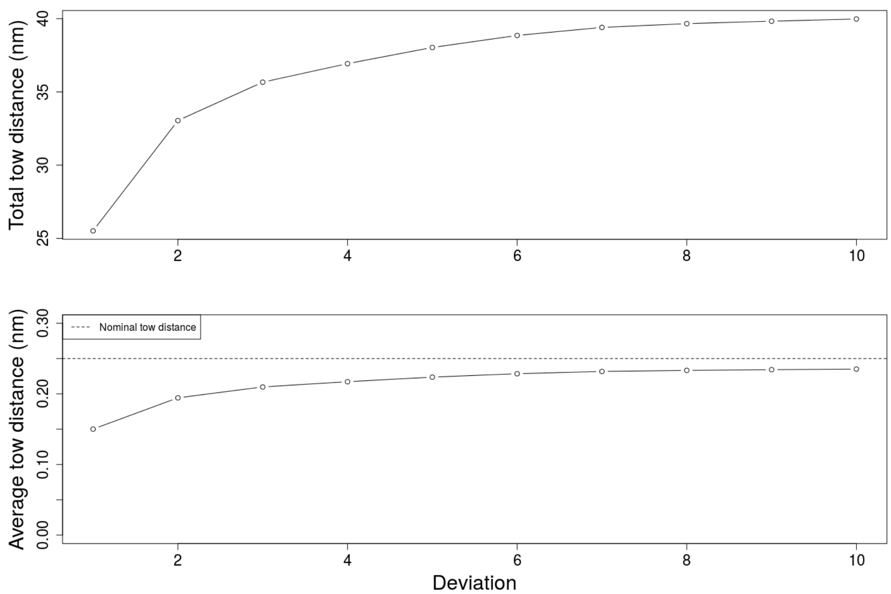



Figure 173: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

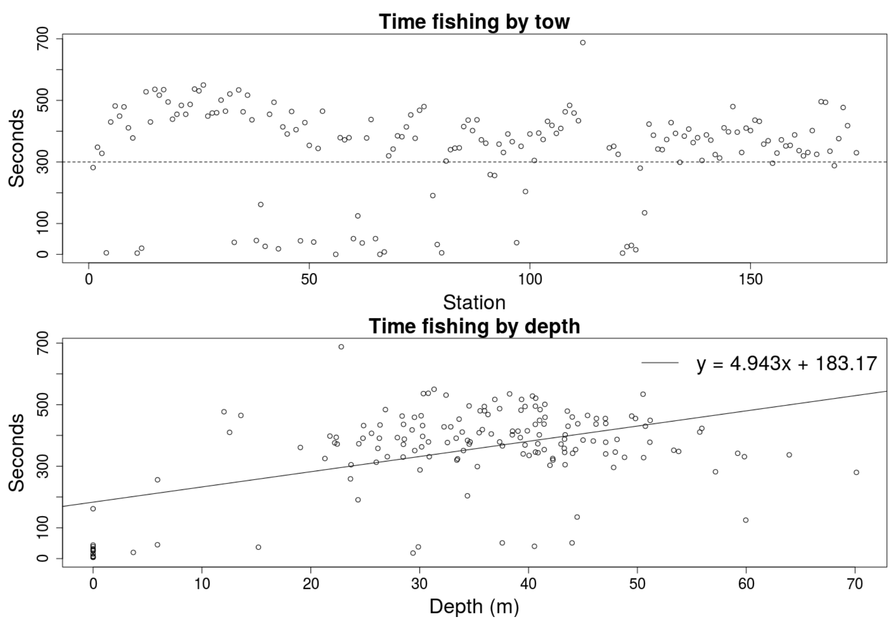



Figure 174: Time fished by station and depth. Depth significantly predicts tow time. The $p$ value for slope was $< 0.001$, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

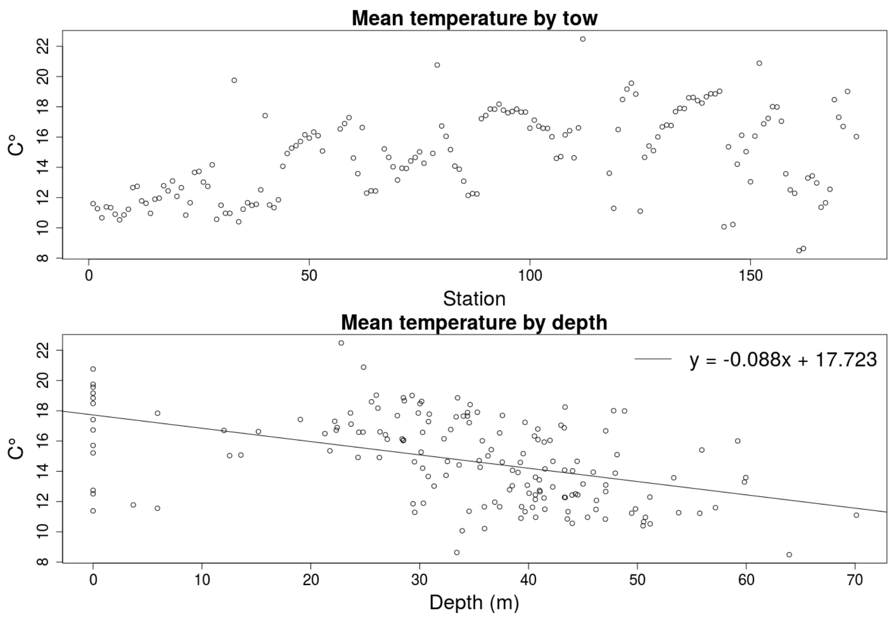



Figure 175: Temperature by station and depth. Depth significantly predicts temperature. The $p$ value for slope was $< 0.001$ and $R^2 > 0.43$ for the regression line shown.

## Appendix 8 Survey performance 2018

### Introduction

The 2018 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2018 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch, roll, and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

### Survey performance

Sensors deployed during the 2018 survey suggest speed over ground was slightly less than 2012, but consistent with the years since (Figure 180). Pump pressure was close to the 2012 median (Figure 180) and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

### Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by an inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within $\Delta_{crit}$ (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow $t$), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing

effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

The choice of $\Delta_{crit}$ was informed by an examination of the total and average tow distances based on different critical deviations. Total tow distance summed across all tow and average tow distance over all tows was compared when different values of $\Delta_{crit}$ were used. In general higher values of $\Delta_{crit}$ result in longer tows because the dredge is considered to be in fishing position for a greater proportion of the tow (Figure 181). We selected a $\Delta_{crit}$ of $4°$ because it produced an average tow distance that was near the nominal tow distance (0.25 nm, a value equal to the nominal tow speed 3 kt multiplied by the nominal tow time 5 min) and because it seemed reasonable based on examination of the engineering schematic of the dredge being used (*Figure not yet available*).

Time fishing during the 2018 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 182).

### Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2018 survey (Figure 182).

### Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2018 survey (Figure 183). Temperature was correlated with depth (Figure 183).

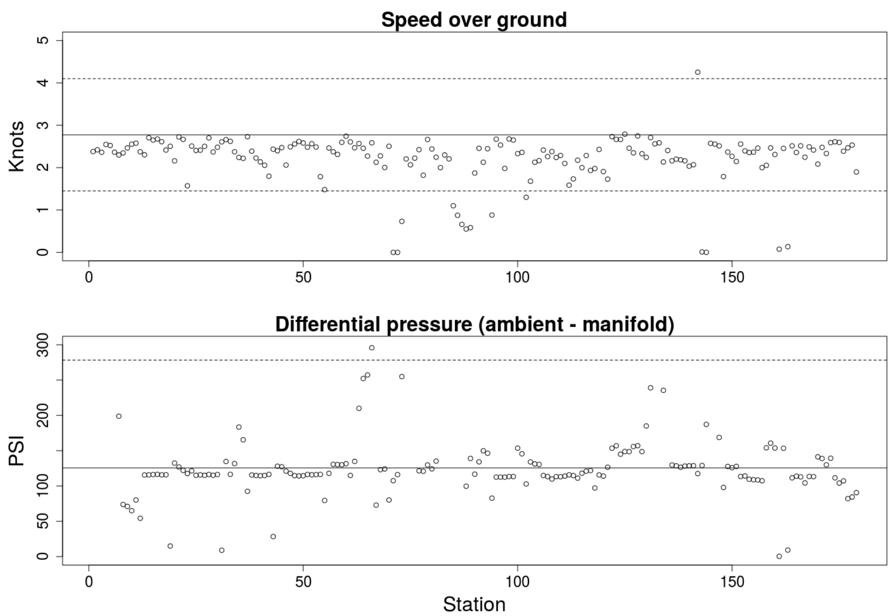



Figure 176: Speed over ground and differential pressure for each tow in the 2018 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

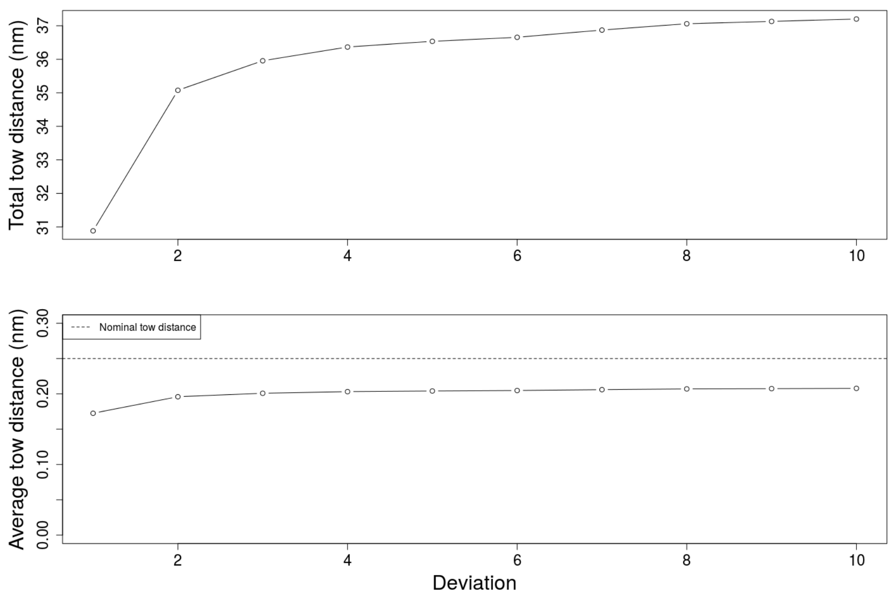



Figure 177: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

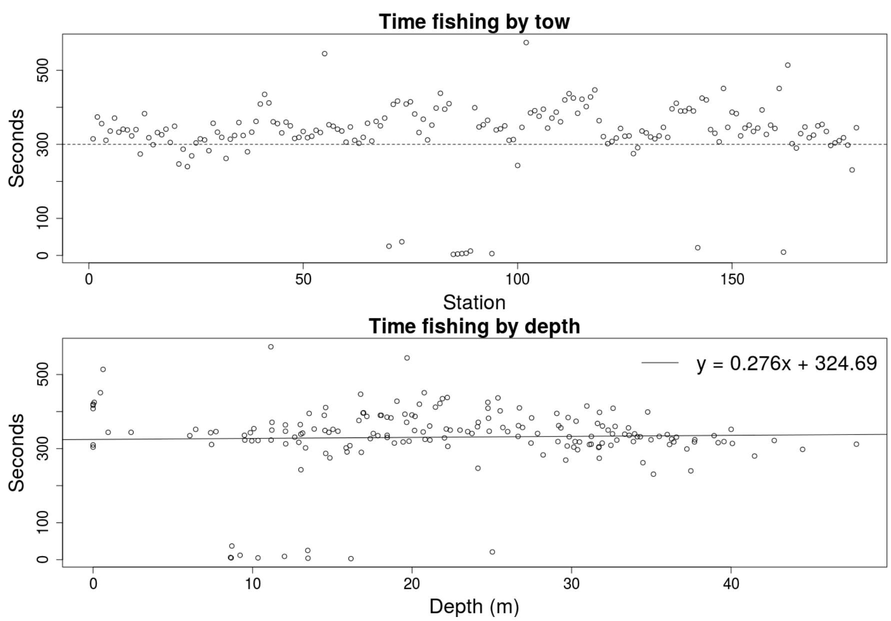



Figure 178: Time fished by station and depth. Depth significantly predicts tow time. The $p$ value for slope was $< 0.001$, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

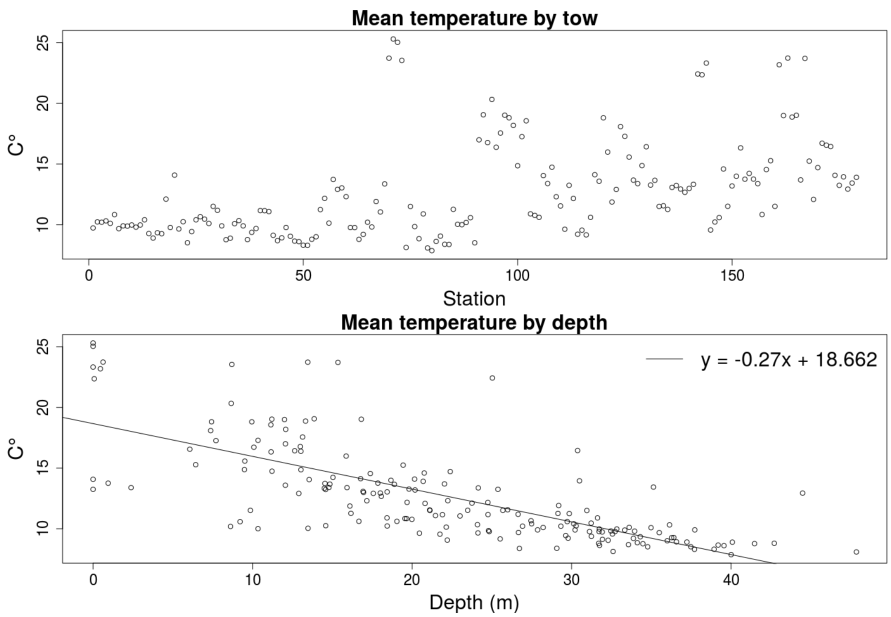



Figure 179: Temperature by station and depth. Depth significantly predicts temperature. The $p$ value for slope was $< 0.001$ and $R^2 > 0.43$ for the regression line shown.

# Appendix 9 Survey performance 2019

## Introduction

The 2019 survey covered a portion of the stock area including the SNE and most of GBK subareas. There were 189 total tows and two selectivity tows. At least some sensor information was recorded on every tow. Therefore there were 187 standard survey tows on which sensors were deployed and sensor data was recorded.

The 2019 survey used a modified commercial dredge with 3 on board data recorders. There was an inclinometer (Star Oddi) and two (Madge Tech) pressure sensors: one in the pump manifold measuring the pressure in the hydraulic jets used to loosen the sediments around clams and one measuring the ambient pressure at fishing depth. The inclinometer measured the pitch, roll, and yaw of the dredge as it was towed and was used to determine if the dredge was in a fishing position, which was the basis for determining "time fishing" on each tow. The pressure sensors were used to make sure that the pump was achieving sufficient pressure to maintain capture efficiency.

## Survey performance

Sensors deployed during the 2019 survey suggest speed over ground was slightly less than 2012, but consistent with the years since (Figure 180). Pump pressure was close to the 2012 median (Figure 180) and well within the confidence bounds observed then. Neither pump pressure nor vessel speed appeared to be less than expected based on ship board instruments during operations and the sensor data have substantial coefficients of variation. The values observed are probably well within normal operating tolerance and are probably not suggestive of changes in dredge performance.

## Determination of time fishing

The determination of time fishing, the "fishing seconds" for each tow was based on a measurement of the pitch of the dredge during each second of the tow. Roll and yaw were relatively stable for the large modified commercial dredge and rarely fluctuated from baseline levels during fishing events. Pitch was recorded by an inclinometer which functioned consistently. Data from each instrument was smoothed using a 7 second moving average and then parsed for time above or below the median fishing angle for that tow.

In order to account for median pitch $> 0^o$, the determination of time fishing was based on a critical deviation from median pitch, rather than an absolute critical pitch angle. The choice of critical deviation has implications for the calculation of tow distance for each tow. When the dredge is above or below the critical deviation it is assumed to be pitched too steeply for the blade to penetrate the sediment. If the dredge is pitched within $\Delta_{crit}$ (the critical deviation) of $\tilde{\phi}_t$ (the median pitch for tow $t$), it assumed to be near enough to parallel to the bottom that the blade should penetrate and thus be actively fishing.

An ideal critical deviation is as close to zero as possible, but not so small that it includes poor dredge performance seconds. When the dredge is bouncing over rough terrain it is unlikely to be fishing

effectively and those seconds should be excluded. There is however, a certain amount of pitch that is within fishing tolerance and a certain amount of noise in the data. If the critical deviation is too small, many seconds when the dredge is actually fishing would be excluded, which would tend to bias estimates of tow distance down. It is therefore important to find a critical deviation that is neither too small, nor too large.

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Time fishing during the 2019 survey was less than the nominal tow time in most cases due to the lower average tow speed discussed above (Figure 182).

### Effects of depth

Depth is typically associated with longer tows due to the scope of the towing wire that must be deployed to assure good dredge performance. Additional scope requires longer retrieval times and may result in some additional time fishing while the slack in the wire is spooled up. This effect was evident (though noisy) during the 2019 survey (Figure 182).

### Temperature

Temperature was recorded from the dredge and averaged over fishing seconds for all tows during the 2019 survey (Figure 183). Temperature was correlated with depth (Figure 183).

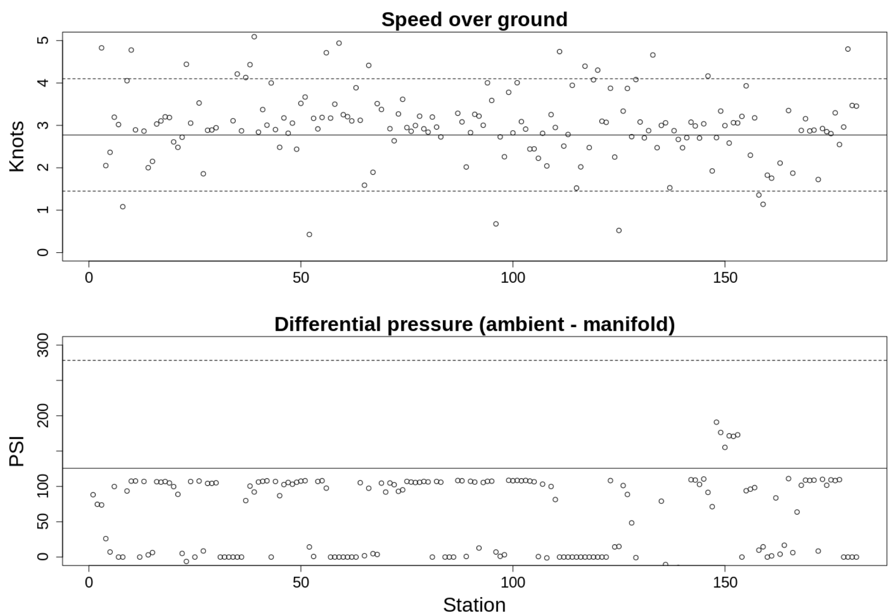


Figure 180: Speed over ground and differential pressure for each tow in the 2019 survey. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed speed over ground in 2012. Differential pressure is the difference between the pressure in the dredge manifold, which indicates the absolute pressure realized by the dredges hydraulic jets, and the ambient pressure at fishing depth. The solid horizontal line is the median and the dashed horizontal lines are the 95% normal confidence bounds observed differential pressure in 2012. Instrument failure or lost data are represented by differential pressure equal to 0.

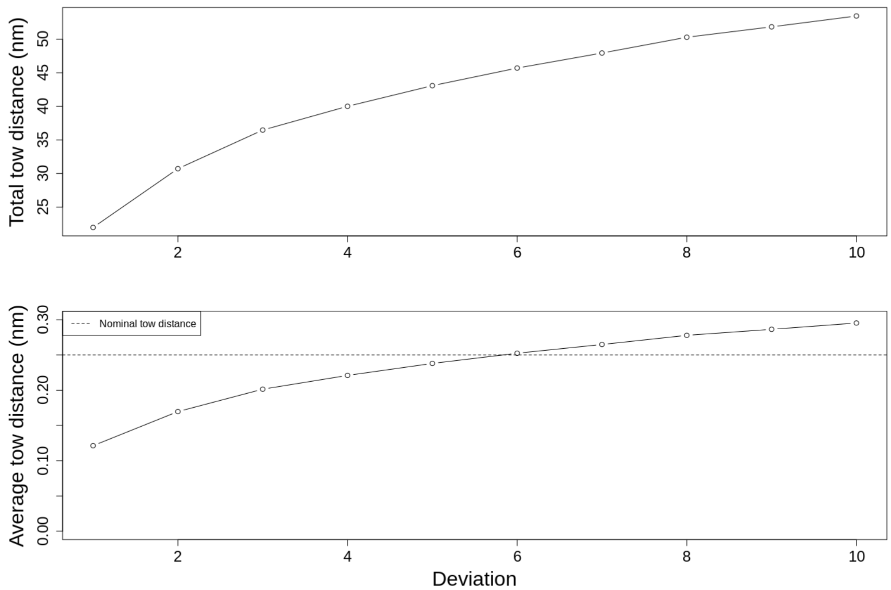


Figure 181: Average and total tow distance over all stations by critical deviation angle. The dashed line in the lower figure represents the nominal tow distance.

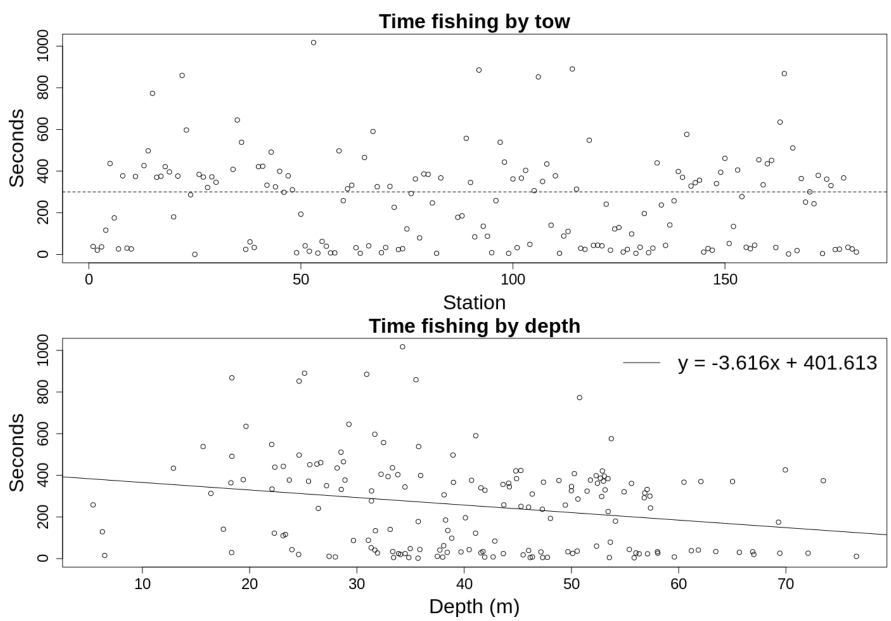


Figure 182: Time fished by station and depth. Depth significantly predicts tow time. The $p$ value for slope was $< 0.001$, though the results were noisy and $R^2 < 0.14$ for the regression line shown.

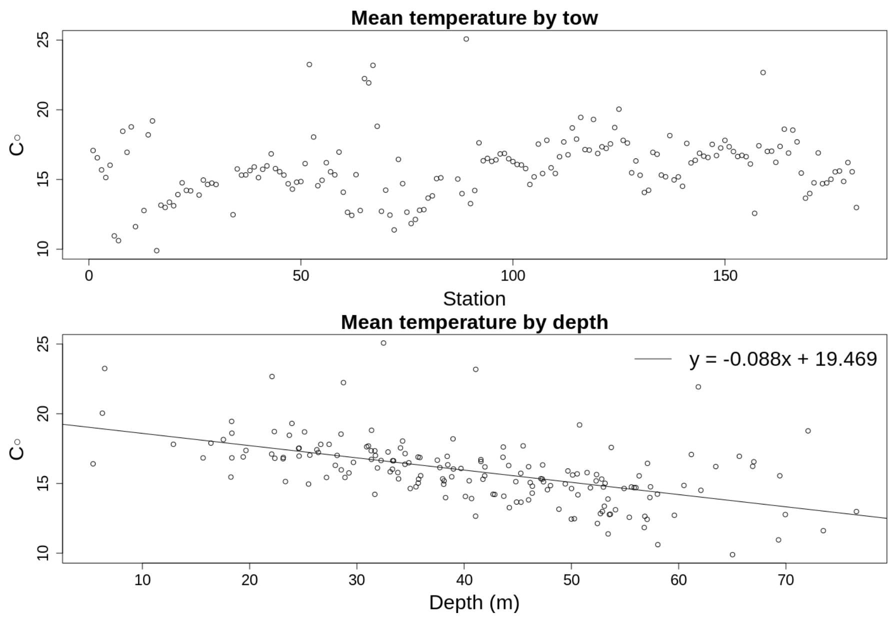


Figure 183: Temperature by station and depth. Depth significantly predicts temperature. The $p$ value for slope was $< 0.001$ and $R^2 > 0.43$ for the regression line shown.